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Finger Lake region of western New York. C. R. Dryer	449–460	37–41	....	.30	.45
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‡Bearing the imprint [From Bull. Geol. Soc. Am., Vol. 15, 1903].

§Fractional pages are sometimes included.

CORRECTIONS AND INSERTIONS

All contributors to volume 15 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 2, line 14 from bottom; *for* "Thus it is said that as early as Origenes, 600 B. C.," *read* Thus it is said by Origenes, that as early as 600 B. C.

Page 311, line 12 from top; *for* "cleavage" *read* cleavages

" 329, " 13 from top; *for* "plate 21" *read* plate 15

" 348, " 11 from bottom; *for* "1890" *read* 1900

" 376, lines 15 and 17 from bottom; *for* "It de with clines" *read* It declines with

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 15, PP. 1-28 JANUARY 27, 1904

THEORIES OF ORE DEPOSITION HISTORICALLY CONSIDERED

ANNUAL ADDRESS BY THE PRESIDENT, S. F. EMMONS

(Read before the Society December 30, 1903)

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INTRODUCTION

In the city in which we meet this year an exposition is preparing which is designed to commemorate the peaceful acquirement a century ago of the rights of France to the Mississippi valley and the regions to the west. It was the metallic wealth of the valley region which first led to its exploration by the French, and which still constitutes an important feature in its industry, yielding annually, as it does, an amount about equal to the original purchase price. To a still greater degree has the unexampled rapidity with which, in the last half century, civilization and industry have spread over the mountainous regions of the West been due to the development of their mineral resources—a development to which geological science has in no small measure contributed.

In selecting a subject for my address as President of the Geological Society of America, it has seemed appropriate, therefore, both to the time and to the place, to choose a theme that has to do with that branch of geology which is especially concerned with the deposits of the metals. The history of theories of ore deposition was the subject originally chosen, but, as it gradually developed in the course of research, it was found that anything worthy of that name would far exceed the proper limits of an address. Thus its scope has been gradually narrowed to fit the necessities of the occasion, until it has become little more than a brief enumeration of the opinions, held from time to time within the historic period, which seem to have left the most permanent impress upon the minds of geologists.

The term "ore deposition," which is used in preference to its earlier synonym "vein formation," as more correctly representing the broader conceptions of the present day, applies, it is hardly necessary to state, only to the processes involved in the formation of deposits that form an integral part of the rock in which they occur, or "rock in place," as is the legal phraseology of the day, and does not include such recent detrital deposits as placers, etcetera, about whose origin there has never been any wide divergence of opinion.

Prehistorical Views

The historic period is assumed to have been entered on only with the revival of learning about the time of the Reformation at the commencement of the sixteenth century. What few records can be found of genetic opinions held before that time, even as to the more striking and readily observable geological phenomena, such as volcanic eruptions, earthquakes, and changes in the earth's surface, are too scattered and fragmentary to afford evidence of any continuous development of thought. The views of the Pythagorean and Aristotelian schools of philosophy on the causes of these natural phenomena, though apparently based more on bold poetical fantasy than exact observation, present a clearer and more logical conception than that which obtained nearly twenty centuries later. Thus, it is said that as early as Origenes, 600 B. C., the observed occurrence in the rocks of casts of shells and plants were ascribed to periodical floodings of the land. During the Middle ages, however, under the monkish influence that discouraged any views that might throw doubt on the literal correctness of the Mosaic cosmogony, these fossils were variously assumed to have been formed in place by the agencies of the stars, to have been transformed from rock by some plastic force (*vis plastica*), or left by the waters of the Noachian deluge.

Among the early cosmogonies, which it is true are of mythologic rather than of scientific interest, the Chinese is the only one which included metal among the elements of creation. Yet the general use of the metals, whose extraction from their native ores presupposes a knowledge of the art of smelting—in itself an evidence of a certain insight into nature's processes—goes back to very remote antiquity. It seems possible that the philosophers of these earlier civilizations may have indulged in speculations as to the origin of the metals, but if so they left no written record. Even among the Romans, of whose proficiency in mining evidence is found in most of the mining regions that came under their control, little or no genetic speculation was indulged in; if we accept the evidence of Pliny's "Natural History." This monumental work, which is assumed to contain a complete and faithful presentation of the knowledge of natural phenomena at the opening of the Christian era, though it described in considerable detail the methods of mining then in vogue, does not even attempt a description of the mode of occurrence of the ores, much less speculate on their origin.

The historic time here contemplated may be divided in a general way into three periods, according to the prevailing method by which the views then current were arrived at:

DEVELOPMENT OF KNOWLEDGE HISTORICALLY CONSIDERED

THE THREE PERIODS

1. The speculative period, in which, from a few rather imperfectly determined facts of nature, general theories were evolved intended to be applicable to all natural phenomena. It was a period in which geology was not yet recognized as a distinct science and had hardly reached the dignity of an adjunct to mineralogy.
2. The second period was that in which facts of observation had accumulated sufficiently to establish geology on the basis of a distinct science, but in which the method of reasoning from generals to particulars still prevailed. This was the first scientific period.
3. The third period might be called the period of verification, in which the theories already propounded were tested by experiment or observation.

Such a classification is in the nature of things not susceptible of a very definite demarcation, either in point of time or in the assignment to either period of individual opinions or theories, but the attempt to make it, however imperfect and unsuccessful it may prove, will assist us to form a clearer conception of the progress of human thought and of the methods by which it has arrived at its present understanding of the particular branch of geological science which we are considering.

THE SPECULATIVE PERIOD

During the first, or speculative period, which may be assumed to have extended up to the close of the eighteenth century, or to the time of Werner and Hutton, the accumulation of accurately determined facts that would bear on the theory of ore deposits was so extremely limited that it may be assumed to have exercised but little influence on the development of the science beyond the suggestion it afforded to later students of lines of investigation to be followed, and hence may be passed over in a very cursory manner.

In the speculations of this period, which especially influenced the development of opinion, two general types may be distinguished:

First, the broader theories of the Cosmic philosophers with regard to the formation of the earth based more or less upon astronomic data;

Second, the special theories of mineral vein formation conceived by individuals and based in the main on general conceptions which were supplemented by a certain amount of personal observation and experience.

The Cosmic philosophers were men who, without being geologists in the modern sense of the word, nevertheless put forth ideas with regard to the system of the earth that had an undoubted influence on the minds of those who have since made a special study of this part of science.

First of these was Descartes, the French mathematician and founder of the Cartesian system of philosophy ("Principia," 1644), who considered the earth a planet like the sun, but which, though cooled and consolidated at its surface, still preserved in its interior a central fire that caused the return toward the surface of waters of infiltration, the filling of veins by the metals, and the dislocations of the solid crust.

Nearly contemporary with him was Steno, a Danish physician, who spent the greater part of his life in Italy, where he devoted much of his time to the study of geological phenomena. He was the first to seek to learn the origin of rocks and the changes in the earth's crust by the inductive method. He wrote a remarkable treatise, bearing the quaint title "De Solido intra Solidum naturaliter Contento" (1669), in which he considers vein fissures to be later than the enclosing rocks, and their filling to result from the condensation of vapors proceeding from the interior. Steno's ideas, so much in advance of those of his age, seem to have found little favor among his contemporaries, and were scarcely known among geologists, until called to their attention in the first half of the nineteenth century by de Beaumont and von Humboldt.

Later, Leibnitz, a German philosopher, inspired both by the ideas of Descartes and the observations and deductions of Steno, wrote a work on the origin of the earth ("Protogæa," 1691), which, in spite of its necessarily limited basis of facts, bears the imprint of genius in its conceptions. In applying his theories to the veins of the Hartz, which he had occasion to visit during his thirty years' sojourn at Hanover, Leibnitz considers that they have been filled sometimes by the liquefying action of fire, sometimes by water.

In the following century, Buffon, the great French philosopher, excited to the highest degree the attention of the scientific world by his "Théorie de la Terre" (1749) and "Époques de la nature" (1778). His conceptions, though striking by the brilliancy of their imagination, have for the most part not proved of enduring value; nevertheless they served a purpose by stimulating more exact observations on the points with regard to which his views were contested. With regard to mineral veins, he held that they were primarily fissures opened in the mountains through the force of contraction, and that they were filled by metals which, by long and constant heat, had separated from other vitrifiable materials. But as there are non-vitrifiable as well as vitrifiable materials in veins, so there are secondary veins which have been filled with non-vitrifiable minerals by the action of water. The primary veins he considers to be characteristic of high mountains, while the secondary veins occur rather at the foot of the mountains, and probably derived some of their material from the primary veins.

In the second class the foremost place, both in time and in the importance of his actual observations, must be accorded to Dr George Bauer, better known by his latinized name of Agricola, a German physician, who flourished during the first half of the sixteenth century. He spent a great part of his life among the mines of Saxony (Joachimsthal), of which he made a careful study. He wrote, in most excellent latin, several works on mineralogy and on the art of mining, which were for centuries standard books of reference on these subjects, and even to the present day contain much of interest to the mining engineer. Agricola was first and foremost a mineralogist, and all his work was characterized by acuteness of observation and accuracy of description, though, in strong contrast to most of the early writers, he did not indulge much in earth-formation theories. He divided mineral veins into "commissuræ" (joints or rents), "fibræ" (small branching veins), "venæ" (large veins or channels), and "terræ canales" (vein systems), and gives a clear account of their size, position, intersections, etcetera. In theoretical matters he was less definite and satisfactory.

During all this period the two main subjects of speculation with regard to mineral veins, which term practically included all ore deposits, were (1) their age relative to the rocks in which they are found, and (2) the cause and manner of their filling; and in considering the views put forward on these subjects, we must bear in mind that chemistry as a science only came into existence toward the end of the eighteenth century; hence the ideas which were entertained as to the processes that may have gone on within the earth's crust to form metallic deposits were necessarily somewhat vague and fanciful.

Among the ideas current in his time, Agricola, as a result of his observations, promptly rejected the views that veins were formed contemporaneously with the primary rocks of the globe, and that the planets had an influence in the formation of the metals; but he seems to have had very few positive ideas of his own as to their origin, though inclining to ascribe vein-filling to material brought in by circulating waters. He still entertained the idea of a lapidifying juice which he conceived as giving to water the power of absorbing earth and of corroding metals, and which might have formed fossil casts as well as minerals. His use of the term "fossilia" for both minerals and petrifications, which was retained by subsequent geological writers, especially those of the Wernerian school, is often a cause of misconception among modern readers who have occasion to consult the older works on geology and mineralogy.

For over a century after Agricola there appears to have been little written that had any special bearing on ore deposits, but toward the close of the seventeenth century there was an apparent awakening of interest in regard to their origin among reflective men who had to do directly or indirectly with mines, which may probably have been prompted by the theories of the Cosmic philosophers, so that by the close of the eighteenth century there had accumulated considerable speculative literature on this subject.

The following is a list of the more frequently quoted works that appeared during this period, with the approximate dates of their publication:

"Speculum Metallurgiæ politissimum," by Bergmeister Balthasar Rösler (1700).

"Physica subterranea," by J. J. Becher. Commentated by G. S. Stahl. Second edition (1703).

"Pyritologia," by J. F. Henkel, professor of chemistry and mineralogy, Freiberg (1725).

"Obersächsiche Bergakademie," by C. F. Zimmermann, councillor of mines (1749).

"Markscheidekunst," by Von Oppell, vice-director of Saxon mines (1749).

"Abh. v. d. Metalmuttern," etcetera, by D. J. H. Lehman, director of Prussian mines (1753).

"Elementa Metallurgiæ Chemicæ," by W. J. Wallerius, Stockholm (1768).

"Ursprung d. Gebirge u. Erzadern," etcetera, by C. F. Delius, professor of metallurgy at Schemnitz (1770).

"Mineral. Geograph. d. Kursächsische Lander," by J. F. W. de Charpentier, director of Saxon mines (1778).

"Unterirdische Geographie," by I. G. Baumer, Giessen (1779).

"Gesch. d. Metallreichs," by C. A. Gerhard, councillor of mines (1781).

"Erfahr. ü. d. Innern d. Gebirge," by F. M. H. v. Trebra, vice-director of Hanoverian mines (1785).

"Beobacht. ü. d. Hartz Gebirge," by Lieutenant G. O. S. Lasius, engineer on land survey of Hanover (1787).

The views of most of these early writers were rather curious than instructive, yet some of them, especially those of men who had the largest practical experience in mines, are remarkably suggestive.

Rösler, the earliest recorded mine superintendent, recognized that veins differ from ordinary cracks in the rocks only by being filled with metallic minerals, but did not speculate on their genesis. Becker and his commentator, Stahl, both professors of medicine, assumed in a general way that mineral veins were original cracks in the rocks containing matter that had been changed into vein minerals by some exhalations from the interior. Henkel supposed further that certain kinds of rock or stone which served as matrices were favorable and even absolutely necessary to the formation of vein minerals. Zimmermann, who, like Henkel, was a chemist rather than a miner, considered that the material of veins, originally the same as the enclosing rock, had been altered by some saline solution and thus prepared for its final transformation into metallic minerals. The above, which might be called conversion theories, do not necessarily assume that veins are mechanically formed cracks, and hence of more recent formation than the enclosing rocks.

Von Trebra, a director of mines who was seeking for facts to aid in their exploitation, thought the changes observed in mountains took place slowly under the influence of heat and humidity, and expressed his idea of conversion as applied to veins more distinctly as the taking away of one constituent of a rock and replacing it by another. The agent of the transformation he called putrefaction or fermentation, by which names he wished to designate some unknown force which produced the chemical changes observed in the rocks.

Lehmann, a mineralogist and also a director of mines, supposed that the veins found in mines are only the branches and twigs of an immense trunk that extends to a great depth in the bowels of the earth, where nature is carrying on the manufacture of the metals, and whence they travel toward the surface through rents in the rocks in the form of vapors and exhalations, as the sap rises and circulates through plants and trees. This general view is popular among practical miners, even at the present day, probably because it appeals almost exclusively to the imagination.

Delius, Gerhard, and Lasius had the general idea that veins were fissures formed later than the enclosing rocks, which had been filled by materials brought in by circulating waters. The last went so far as to suppose that these waters contained carbonic acid and other solvents which enabled them to gather up metallic materials in their passage through the rocks. In this respect he approached closely to modern views, but he was in doubt whether the metals were contained in the rocks as such, or whether the solvents possessed the power of turning the substances they encountered in one place into lead and in another into silver or some other metal.

Of more permanent value were the works of Von Oppell (1749) and de Charpentier (1778), who were successively directors of the Saxon mines previous to Werner.

Von Oppell was the first to distinguish bedded deposits (*lagergänge*), or those which lie parallel with the stratification, from true veins. He also gave to the small branches from a main vein the name of "stringers" (*trümmer*), and noted that veins sometimes shift or fault the strata they cross, in which case he calls them "shifters" (*wechsel*). He laid stress on the importance of the causes which have produced rents or fissures in the earth, and shows how in the formation of mountains the rocks, being exposed to great desiccation and violent shocks, might split one from another, thus producing rents with some open spaces, which being afterward filled, would form mineral veins. "Where a vein has been cut or deranged by a visible rent," he remarks, "it is again to be met with by following the direction of this last."

Charpentier was a careful observer and a very cautious theorizer. He says, "Natural history will always gain more from true and accurate descriptions of her phenomena than from many and yet too early explanations offered for them"—a most excellent principle which he admirably carries out in his own work. He presents many arguments derived from his own extensive observations in mines against the prevalent theory that veins were once open cracks formed by contraction, and that they had been filled by material flowing in from the surrounding rocks and hardening in them. Some of his objections were:

That contraction could not have made the kind of fissures that the veins are found to fill.

Open or empty spaces could not have existed under the conditions present when they were formed; pressure would have closed them.

The fragments of country rock as found in veins could not thus be accounted for. If they had simply fallen into an open crack, they would have accumulated at its bottom.

The comparatively uniform arrangement of ore in the vein; the enrichment caused by the crossing of one vein by another; the transition from vein material to country rock, etcetera, could not be explained on the contraction theory.

Having given his reasons why he believes that veins are not the filling of wide open spaces in the rocks, he says his readers will naturally ask how he supposes them to have been formed, and although he is not anxious to present a theory, he says he can not see from his observation of the workings of nature any other method for the formation of veins or other ore deposits than by an actual transformation of the rock material. Nature's processes have created innumerable small cracks and fissures in the rocks, and when a great number of such cracks lie together and in a common direction they might give rise to a considerable vein deposit. Vapors bringing in mineral solutions might penetrate these small cracks, as the sap rises in capillary tubes in organic bodies. If thereby the intermediate rock mass became changed into vein material, a vein deposit might be created without the necessity of wide empty spaces for its reception.

Rather more than usual space has been given here to Charpentier's work because of the striking contrast of his mental attitude with that of his great successor, Werner, whose reputation so completely overshadowed him that he has received less notice from later writers than seems to be his due.

THE SCIENTIFIC PERIOD

The first scientific period may be said to have been entered on near the close of the eighteenth century, when De Saussure (1779), Pallas (1777), and Werner (1791) almost simultaneously inaugurated by their works the era of positive geology. It was about the same time that chemistry was placed on a scientific basis by the researches of Lavoisier, Scheele, Priestly, Cavendish, and others. Up to this time even the name geology had hardly been recognized, natural history or mineralogy being the titles usually given to works that treated of it, and the few exact facts with regard to it which such men as Agricola, Steno, and others had determined were drowned in a sea of conjectures. On the Continent it was the mining schools that principally fostered mineralogic and geognostic studies, and these had been but recently founded, that at Freiberg, Saxony, in 1765; at Schemnitz, Hungary, in 1770; at Saint Petersburg in 1783, and at Paris in 1790. Geological literature, especially in Germany, went hand in hand with that on mining and mineralogy.

Of the three men just named, the two first were eminently observers. Pallas, after being called to the mining school at Saint Petersburg, had made a six years' geological expedition through the mountains of Russia and Siberia, and De Saussure for over thirty years was largely busied in studying geological phenomena in his native Alps, being the first to climb Mont Blanc and Monte Rosa. He also appears to have been the first to use the name geology for his science. While neither of these men contributed much to the advancement of geological theory, they added largely to the store of ascertained fact, which is its necessary basis, and their greatest service perhaps was in inaugurating geological studies of the great mountain systems of the world, which more than any other branch of geological inquiry have been instrumental in raising this science to its present stand.

The actual field of observation of Werner, on the other hand, was extremely restricted, scarcely extending beyond the confines of his native Saxony. He had, however, a genius for the analysis, classification, and coordination of observations, which enabled him to bring order out of the chaos of fact and fancy which then constituted the science. With an eminently didactic mind, he possessed, with much personal charm, such a power of impressing his ideas upon his pupils, that during the forty years that he occupied the chair of mining and mineralogy the Freiberg school was the center of geological studies in Europe. From it emerged so many distinguished geologists, as the fruit of his teachings, that, as Cuvier says, "from one end of the world to the other nature was interrogated in the name of Werner."

Contemporaneously with Werner an equally great service was being rendered to geology at Edinburgh, in Scotland, by James Hutton, who, like so many of the eminent geologists of the world, had been educated as a physician. Hutton, like Werner, taught mainly through his lectures, neither of them finding time for much writing, so that the doctrines of either have become known to posterity mainly through the publications of their pupils.

Each of these great teachers aimed to discard theory and to build their respective systems on a basis of ascertained facts, but in the then existing condition of geological investigation certain fundamental conceptions had to be assumed from the interpretation given to as yet imperfectly studied phenomena. With minds like theirs, strong in the courage of their convictions, an interpretation once fairly reasoned out and accepted became an established fact, and thus it came about that through a difference in their premises their respective systems were diametrically opposed, and gave rise to the great controversy between Neptunists and Plutonists, which, for nearly fifty years, divided the scientific world of Europe into two antagonistic schools. Werner assumed that the earth had once been surrounded by an ocean of water at least as deep as the mountains are high, and that from this ocean there were deposited by chemical precipitation the solid rocks which now form the dry land. He entirely ignored the internal heat of the globe in its influence on crystalline rocks, on ore deposits, and as a cause of the dislocations of stratified rocks. Hutton, on the other hand, while not ignoring the agency of water in the formation of the sedimentary rocks, ascribed to subterranean heat and the expanding power it exercised their final consolidation, their disturbed condition, and the changes produced in the older rocks, to which Lyell later gave the name of metamorphism.

Neither made any distinction between dikes and mineral veins, but while Hutton supposed fissures and openings to have been formed from time to time which reached through the external crust down to the hot nucleus, and that both were formed by molten matter forced up through them toward the surface, Werner, on the other hand, taught that they were contraction fissures which were filled by material held in suspension or in solution; that a primeval ocean once covered them, and hence they must have been filled from above.

In general matters Hutton's reasoning and observations were both broader and more logical than Werner's, and his views have hence proved more enduring, but he had little, if any, personal knowledge of ore deposits. Werner made their study an important feature of the geologist's training, and his principal publication was entitled "A new theory of vein formation." Although this work was the only important one exclusively devoted to the subject, owing to the fatal defects in his geological premises, it contributed little to the permanent advancement of that branch of the science, and it may even be questioned whether it did not retard it, since through the great weight of the author's name it remained a standard work in Germany long after many of his peculiar geological theories had been discarded. Its merit lay less in the novelty of the views advanced, most of which had already been put forth by one or another of his predecessors, than in the logical way in which they were presented.

The principal points with regard to the origin of ore deposits which may be considered as fairly well established by Werner's teachings are that they are the filling of fissures and cracks of later formation than the enclosing rocks, and consist of foreign material subsequently introduced, largely in aqueous solution. As to the fissures themselves, while a certain systematic arrangement had been noted in their directions, and the fact that, where by intersection, one had been shifted or faulted by another, inferences as to their relative age might be drawn, little definite conception was apparently had as to their origin beyond the general suggestion that they might be the result of subsidence or of contraction of the rock masses in which they occur.

Any important advance over these rather crude conceptions was hardly to be looked for until very decided progress had been made in the broad general theories of geology, and this progress was necessarily very slow. Although the period of reasoning from facts of nature to generalizations had commenced, the tendency to pure speculation was not yet extinct, and resulted in many remarkable theories, such as that put forth by Professor Oken, of Jena, who, in his text-book of Natural Philosophy (1809), assumed that the earth was a polyeder formed according to the laws of crystallography, and that veins or fissures resulted from the loss of the water of crystallization. For the genesis of ores, darkness, earthy water, and air are necessary; hence there can be no ore in the interior of the earth, since no air reaches it, etcetera. Or, again, that of Breislach, the Italian geologist (1811), who put forth a Plutonic earth-theory which supposed that, while the rocks were still in a molten condition the metals had a tendency to separate under the influence of specific gravity and of certain chemical and physical affinities, and localized themselves in veins without entirely separating from their country rock. This is apparently the first enunciation of the modern theory of magmatic segregation. The metallic grains in placers he supposed to have been granulated like slag on coming in contact with water.

The peculiar views of Werner naturally held sway longer in Germany than elsewhere, yet it was his favorite pupils that were first led, in their widening fields of observation, to abandon his theory that basalt is of aqueous origin, though altered by the heat produced through the combustion of neighboring beds of coal.

Von Buch, for a long time the leading geologist of Germany, was perhaps the first to whom doubts came as to the correctness of his master's teachings, while studying an eruption of Vesuvius in 1799, though he refrained from immediate publication of these doubts.

D'Aubuisson, the French geologist, after visiting, in 1804, the volcanic regions of Auvergne, also became convinced of its igneous origin and published a recantation of the views maintained in his essay of the previous year on the aqueous origin of the basalts of Saxony. Finally, von Humboldt (1810), perhaps the greatest of his pupils, in his extended observations in the Cordilleran system of the American continents, traced a direct connection between metallic deposits and the eruptive rocks.

Observation must have convinced many of Werner's pupils of the untenability of his peculiar views on the formation and filling of veins long before their final refutation was published by his successor, von Beust, in 1840, but reverence for his memory doubtless prevented a definite expression of their opinion in print.

Von Herder, in his work on the Meissner adit, published in 1838, classified the various theories on the origin of veins that had been held up to that time, as follows:

1. Theory of contemporaneous formation (with the enclosing rock).
2. Theory of (filling by) lateral secretion, or by material derived from the enclosing rocks.
3. Theory of (filling by) descension, or filling from above.

4. Theory of (filling by) ascension, or filling from below, the latter subdivided into:

a. By infiltration, or solutions from mineral (thermal) waters.
b. By sublimation, or by ascending steam.
c. By sublimation, or in gaseous condition.
d. By injection or in igneous fluid state.

He was thus apparently the first to apply the now time-honored terms "ascension," "descension," and "lateral secretion," though the idea was clearly expressed thirty years before by Cuvier's collaborator, Alexander Brogniart, when, in an attempt to reconcile the Huttonian and Wernerian schools, he showed that no one theory could fit all kinds of veins.

The theories of contemporaneous formation and of descension had by this time become practically obsolete among the Germans, and had never had much standing among geologists of other nations. German geologists, who have been the most assiduous students of vein phenomena in the field, have always been inclined to assume that vein minerals have been deposited by precipitation from aqueous solution, differences of opinion having been mainly as to the provenance of the waters. Doubtless the influence of Werner had much to do with their mental attitude, but it is also to be remarked that this method of formation best fits the ore deposits of their country.

In England, the home of Plutonism, on the other hand, no very decided views on theories of ore deposition were held. John Maccullough in 1821–1823, after a discussion of the Wernerian-Huttonian views, wisely concludes that it is necessary to study nature's processes more closely before a satisfactory theory can be formulated. He enumerates the minerals occurring in ore deposits which may be formed by infiltration or solution and by sublimation, contending that many vein minerals can be produced in either way, and recommends further investigations along that line.

John Taylor, in his report on mineral veins to the British Association in 1833, makes a similar review and arrives at similarly indefinite conclusions.

Later, De la Beche, in his Geology of Cornwall (1839), says:

> "The theories of the day divide themselves into, first, the contemporaneous formation of mineral veins with the rocks which enclose them; second, the filling of fissures formed in rocks by the sublimation of substances driven by heat from beneath upwards, and, third, the filling of fissures in rocks by chemical deposits from substances in solution in the fissures, such deposits being greatly due to electro-chemical agency."

The contemporaneous theory, according to him, was still generally held among Cornish miners, but he himself is evidently more inclined to the theory of deposition by solutions ascending under the influence of internal heat, the water being furnished from the sea, which covered many of the Cornish lodes.

The electro-chemical theory, which had already been suggested in 1810 by Bergrath Schmidt, and for a time enjoyed a certain popularity among English geologists, was founded mainly on observations made on the mine waters of Cornwall by Robert Ware Fox. This theory assumed that vein minerals had been precipitated from solution under the influence of electrical currents. It would appear, however, that, owing to the imperfect knowledge of chemistry of that time, the believers in this theory assumed electric currents to be a necessity for the production of certain reactions when they only serve to facilitate them. Fox's observations on the action of mine waters on minerals were, moreover, rendered somewhat inconclusive by the fact that he did not distinguish between primary vein minerals and those that have been formed during their secondary alteration by surface waters.

Among French geologists, Plutonist views were predominant from the first; even those who under the influence of Werner's magnetic teaching had for a time embraced his Neptunist theory soon recanted it, when their field of observation had widened to include volcanic regions. The cosmic theory, generally known as the "nebular hypothesis," the one which has been most universally accepted by geologists as an explanation of the earth's beginnings, as finally received, was the work of a French mathematician, Laplace (1796). Hence, in seeking to account for the origin of ore deposits they were naturally inclined to look for igneous agencies. Thus, A. Burat, well known through his work, "Applied Geology" (1843), took extreme Plutonic views and divided the copper, lead, and iron deposits of the Italian peninsula, which he had especially studied, into (1) dikes or eruptive masses, with gangue of amphibolite and ilvaite, and (2) irregular veins of contact between eruptive serpentine and sedimentary rocks. The Elba deposits of specular iron, which he regarded as striking instances of the first class, he considered to have exercised an elevatory as well as metamorphic action on the enclosing rocks at the time of their injection. Fournet, another prominent authority on the subject, maintained a theory of igneous injection for vein fillings as late as 1859.

As in Germany it was the professors in the mining schools, especially those at Freiberg, who in the early part of the century led in forming scientific opinion as to ore deposition, so it was the School of Mines at Paris which later furnished the leaders in that branch of geological thought.

The French students of underground phenomena were at a certain disadvantage as compared with their German brethren, in that they were obliged to travel to foreign countries to study large mines, whereas the German schools were all situated in the midst of important mining districts. On the other hand, while the German displays great industry and acuteness of observation in his collection of facts, the Frenchman has a remarkable faculty of logically grouping them and of clearly and concisely stating the conclusions to be drawn therefrom. The French language, moreover, by its structure is much better adapted to a concise presentation of scientific concepts that are readily understood by the reader than the German, which is likely to be involved and cumbersome in its mode of expression. Hence, toward the middle of the century the influence of the French geologists on genetic speculation became predominant, especially as it was based on synthetic experiment, a branch of geological investigation which for a time they practically monopolized.

The first of the French geologists who has left an enduring impress upon the theory of ore deposits was Elie de Beaumont, who for nearly fifty years occupied the chair of geology at the Paris School of Mines (1827–1874). In 1847 he published, as an abstract of his lectures, his well-known paper "Volcanic and metalliferous emanations," in which he does not claim to formulate a complete or final theory, but presents his views as explanations which seemed to him best to fit the facts of nature as then known. His conclusions are, briefly: That the metallic minerals in veins of incrustation (since called crustification) find their ultimate source in eruptive rocks, from which they emanate at first in gaseous form. As they pass through long canals or fissures, at greater distances from the center of eruption they must condense and thus form deposits analogous to those of springs at their point of exit. The metals in veins are found united less frequently with oxygen than with certain elements to which the name "mineralizers" has been given, and which are not only volatile themselves, but possess the property of rendering volatile many substances with which they combine. These are sulphur, selenium, arsenic, antimony, phosphorus, tellurium, chlorine, bromine, and iodine, etcetera.

Mineral springs he divides into principal or hottest thermals, which are fed by gases emanating directly from eruptive masses which reach the surface in a fluid state, and, second, less heated springs, which often accompany the former. The latter are fed by meteoric waters, which descend until they come in contact with hot rocks and, when heated, ascend again, in which journey they may be charged with mineral substances.

Vein deposits may be formed by either class of thermals; the second class would form deposits not only in ordinary fissures, but also in those already charged by direct emanations. It is difficult to account for the gangue minerals as direct emanations, since they are not volatile except such as are combined with fluorine. Certain deposits without gangue in eruptive rocks and deposits in limestone in contact with eruptive rocks, associated with garnet, ilvaite, and similar minerals, may have been deposited by sublimation, but these are exceptional. For most veins he admits, in accord with Bischof, that the earthy minerals must have come from the decomposition of the country rocks. The greater proportion of true veins (veins of incrustation) he considers to have been formed by deposition from waters circulating in cracks in the earth's crust. In this, his theory resembles Werner's, but differs from it in assuming that the solutions were ascending rather than descending. Werner's argument in favor of descending waters, namely, that veins become poorer in depth, he considers not well founded, the facts of nature rather going to prove that the solutions became weaker as they approached the surface.

Stanniferous veins, which contain a great number of the rarer elements and are associated with acid rocks, are the type of the first class, while ordinary or plumbiferous veins, which are characterized by the important rôle of mineralizers and the absence of anhydrous silicates, are usually associated with basic rocks.

His reasoning is evidently based largely on his observations in Cornwall, and on an assumed difference in the origin of granite and of volcanic rocks in general. Granite, he assumes, owes its crystallinity less to the fact of having crystallized at great depths than to its content of water (2 to 3 per cent), which enabled it to remain in a pasty condition much below its fusion point, and thus allowed quartz to take the impress of other minerals. The minerals of the first group of veins form part of the outer crust (*penumbra*) of granite bodies, as granite once formed the outer crust of the earth.

The products of volcanic eruptions he divides into two classes: (1) the lava-like, which consist of silicates in a molten condition; (2) the sulphur-like, which emanate in a molecular condition. To the latter alone can the formation of vein minerals be attributed. The term "solfataric," which was employed by subsequent writers to describe the action of the sulphur-like emanations, has since been very generally used by writers on ore deposits in a sense which is not always strictly accurate.

Although de Beaumont's views are based on some premises no longer considered tenable, they mark an important advance in this line of research, in that they may be said to be the first fruits of organized field investigation, for the first geological surveys, those of Great Britain and of France, had been founded about ten years before, and the first geological map of France had recently (1841) been completed by the latter survey, of which he was the founder and director.

This was also an era of experimental investigation, as well as of observation in the field. Following the example of Sir James Hall, who had, as early as 1805, spent some years in experimenting on the transformation of rocks under the combined influence of heat and pressure, French geologists were actively employed in attempting, by synthetical experiment in the laboratory, to imitate the processes of nature in the formation of rocks and minerals, especially of vein minerals. Prominent among those engaged in this work were Berthier, Becquerel, Ebelmen, Durocher, Sénarmont, and Daubrée. At first with heat alone and later employing heat and water combined, always under pressure, they succeeded in reproducing artificially a great number of the minerals of rocks and veins. Sénarmont (1849–1851), by the aid of water at temperatures of 130° to 300° C., formed artificially thirty of the principal minerals found in ore deposits, including quartz. The results of these experiments did not, however, prove decisively the agents which nature has employed, since they demonstrated that the same mineral may be formed by several different methods. This was appreciated by Daubrée, who, commencing his synthetical experiments with the artificial production of cassiterite in 1844, carried on experimental investigations into the mechanics of rock fracturing, the flow of subterranean waters, and rock metamorphism in general to near the close of the century. He was particularly impressed by his studies of the mineral processes that have gone on since Roman times in the masonry of old thermal establishments at Plombières, Bourbonne-les-Bains, and elsewhere, in which he thought to trace the actual processes of vein formation. His works, "Experimental Geology" (1879) and "Subterranean Waters" (1887), which contain the first philosophic discussion based on experiment of the physics of the rock fractures that constitute canals for the circulation of underground waters, are still classic works of reference for the students of ore deposits. Daubrée understood veins to be fractures formed by dislocations of the earth's crust under pressure strains and filled by deposits from aqueous solutions, generally heated by contact with igneous rocks, from which in certain cases they may have directly emanated. From his observations at Plombières he inferred that most minerals are soluble if given sufficient water and time, and that great heat and pressure are not absolutely necessary prerequisites. Some of the materials of veins, he admitted, may have been derived from the surrounding rocks.

The middle of the nineteenth century was characterized by the increasing use of laboratory experiments in chemistry and physics as aids in testing the current theories of vein formation, as is shown in the preceding sketch of progress of opinions among French geologists.

Similar progress was going on in other countries, especially in Germany, which was more particularly a country of mines and mining engineers, though among students of this subject there was less solidarity of opinion than with the French, and their investigations for a long time were rather on chemical than on physical lines.

A great impulse to increased accuracy in geological investigation was given by the classic work of G. Bischof, " Physical and chemical geology " (1846–1847), which discusses in a masterly way the processes involved in most of the known geological phenomena, largely on the basis of the author's own researches and experiments, and which may be said to have raised chemical geology to the rank of a distinct science. In the course of his investigations, Bischof, having found that the constituents of the gangue minerals of veins are found in the country rocks, thought it probable that the metals of the sulphide ores might also exist in these rocks in the form of silicates. Later, and independently, Forchhammer, the Danish chemist, in the course of his long continued investigations of the waters of the ocean, detected minute amounts of many of the metals of ore deposits both in sea water and in different varieties of rocks. It was long before the suggestions offered by these discoveries had any practical effect on ore deposit investigations.

The leading authorities (on ore deposits) of that period were Von Beust, Breithaupt, H. Müller, and Von Cotta. The latter for over thirty years occupied the chair of geology at Freiberg, during which time he had opportunities of visiting most of the important mines of Europe. His text-book on ore deposits (1853–1859), which up to the end of the third quarter of the century was the standard authority both in Europe and America (through Prime's translation, 1869), may be assumed to be a good exponent of the knowledge of the time. It gives a fair-minded statement of all the theories which had been given to account for the formation of vein minerals, showing, however, a leaning toward the infiltration or hydrothermal theory of vein filling, based on the fact that some of the most common constituents are found in existing thermal waters, and that thermal waters containing CO_2 or H_2S are found in the deeper workings of some mines. In general, however, his views, whether on classes of deposits or individual types, do not betray the firm conviction that would result from an exhaustive and systematic study. Moreover, the fact that his classification of deposits is based on the more or less accidental character of form, without any reference to genesis, would indicate that his genetic ideas were still in a tentative state.

In 1873, Professor F. Sandberger, feeling that the current theories inadequately explained many of the phenomena of vein deposits, followed out the suggestions of Bischoff by making an extended series of analyses of the country rocks of veins. Separating previous to analysis the constituent minerals of the rocks by means of solutions of varying densities, he succeeded in demonstrating to his own satisfaction that the characteristic minerals of different deposits are contained in the basic silicates of the adjoining rocks, and in 1880 propounded his theory of lateral secretion, according to which the mineral contents of veins are derived, not from some unknown depth, but from the immediate wall rock, being brought in by percolating waters which are not necessarily at a very high temperature. As against the thermal spring theory, he argued that a very small proportion of known thermals contain any of the metallic minerals whatever and none in the state of sulphides; further, that the deposits observed in their channels have been precipitated in immediate proximity to the surface and under physical and chemical conditions that differ essentially from those that must have prevailed at the depths at which veins were formed.

Sandberger's theory, though for a time it found many adherents, was bitterly contested, especially by Stelzner, Von Cotta's successor at Freiberg, and by Posepny, professor at the Mining School of Pribram, in Bohemia. They maintained that the facts in their respective districts disproved the lateral secretion theory in the restricted sense in which Sandberger employed it, and they demonstrated by a repetition of his analyses that, owing to imperfect methods, he had not proved the metals he found to be necessarily original constituents of the rocks in which they were supposed to occur. Whatever opinion may be held as to the merits of Sandberger's theory, as such, it undoubtedly contributed to the advance of the study of ore deposits in stimulating what may be called verification—that is, the practical testing of theory in its application to concrete instances in nature.

In general, it may be said of the period that was now closing that, though facts of observation and experiment had been accumulating, the advances in the study of ore deposits during that time were much less than those that had been made in other branches of geological science

THE VERIFICATION PERIOD

The third period, covering, in a general way, the last quarter of the past century, may be called the period of verification. So fertile had been the imagination of previous thinkers on this subject that at this time it was practically impossible to conceive a theory of origin for a given ore deposit that had not already been proposed or at least suggested. The investigations now to be carried on with more perfect methods, or in the light of recent advances in the science, would seem more properly verifications of old theories than the propounding of new ones.

Method and the microscope have been the two great agents of progress. The greatest improvement in method has resulted from government aid, under which it has been possible for organized bodies of scientific workers to make special examinations of entire mining districts, and thus determine all the facts bearing upon ore deposition in those districts with an exhaustiveness that was impracticable for the unaided individual observer. The newly created science of microscopical petrography, through the intimate knowledge it has afforded of the internal structure of rocks and ores, has admitted so accurate a determination of the processes by which they have been formed that much that was formerly mere conjecture has become established on basis of fact. America, which hitherto had occupied a very subordinate position, had come to the front, not only in the production of metallic ores, but in its correct understanding of the processes by which they were formed.

In order to properly appreciate the progress which has been made during this period one must endeavor to realize the mental standpoint of the average student at the close of the preceding period.

To the miner and prospector, whose opinions carry weight because of their wide practical experience, a typical ore deposit was a vein which, once an open crack extending to an indefinite depth, had been filled by material introduced in one way or another from below, and the more nearly a deposit approached this typical form the greater its value. Indeed, for a time, some of the most valuable deposits in the West were entirely neglected by the prospector because they did not possess the physical characteristics of the "true fissure vein." This misconception arose from the fact that this, being the most clearly defined form of deposit, had been the only one mentioned in early speculations, and that hitherto the classification of text-books, based as they were on the almost accidental characteristic of form, relegated other types of deposit to a distinct and relatively subordinate class, disregarding the fact that this class includes many of the largest and most productive ore bodies which may not only have the same origin, but often be associated in the same deposit with a typical fissure vein.

Von Groddeck (on the other hand), who represents the most advanced scientific opinions of his time (1879), divides ore deposits into two classes:

1. Those formed contemporaneously with the enclosing rock, whether (*a*) sedimentary or (*b*) eruptive.
2. Those of later formation classed under two heads:
    a. Those filling preexisting open spaces;
    b. Metamorphic deposits formed by alteration of rock in place.

His two main divisions corresponded to a certain extent with those made in 1854 by J. D. Whitney (Metallic Wealth of the United States), namely, stratified and unstratified. One difference is that metamorphic deposits were included by Whitney in the first division and by Von Groddeck in his second. Neither recognized their true importance, and the latter, while admitting that he included in this class those that

Stelzner had called metasomatic deposits, said they could not be regarded as separate deposits, because they are only incidental phenomena of the filling of cavities.

As a means of obtaining a clear view of the whole field, Von Groddeck divided known deposits into types (54 in number), characterized in the main by their varying mineralogical and lithological associations. Of these, sixteen belong to his first subdivision, five to the second, twenty-six to the third, and seven in part to the third and fourth, a classification which he admitted must be considered but tentative, owing to defects in existing knowledge which could be remedied only when all mines could be studied on a monographic or exhaustive system.

In America, though apparently unknown to Von Groddeck, such monographic studies had already been made—that of the Comstock lode by King (Fortieth parallel reports, 1870), of the Lake Superior copper deposits by Pumpelly (Michigan Geological Survey, 1873), and that of the lead deposits of the Mississippi valley by Chamberlin (Wisconsin Geological Survey, 1873–1879). These were followed in the early eighties by reports on the Comstock lode by Becker, on Leadville by Emmons, on Eureka by Curtis, and on the copper-bearing rocks of lake Superior by Irving, monographic studies which constituted an important feature in the plan of work laid out for the newly established United States Geological Survey. It was the expectation of those who planned this work that when all the important mining districts of the United States had been thus exhaustively studied, a sufficient store of well ascertained facts regarding ore deposits would have been accumulated to admit of the formulation of a new theory more firmly grounded on a basis of well established fact than any that had yet been presented.

It may be said of the deposits studied in the first decade of the Survey work that in the form in which they were found they were all determined to have been deposited from aqueous solutions and to be of later origin than the enclosing rocks. The lead and zinc ores of the Mississippi valley might have been included in Von Groddeck's contemporaneous class if, as assumed by Whitney and Chamberlin, these metals had been deposited with the limestones at the time of their formation; but, while as to this ultimate source there is some difference of opinion, all are agreed that the concentrations which produced the workable ore bodies were of later date; hence it seems more logical to consider them of later formation than the enclosing rocks.

In the case of the other deposits studied, which were found to occur either in or in the immediate vicinity of eruptive rocks, it was assumed that the percolating waters had derived their metallic contents from some of these eruptive rocks, which careful tests had shown to contain small amounts of the various materials of the deposits. This derivation had an advantage over that of indefinite depth appealed to by the ascensionist or hydrothermal school, inasmuch as it admitted some sort of experimental proof, indirect though it was, and because at the depth at which the rocks might be supposed to be essentially richer in metals than those found at the surface, cracks sufficiently open to admit a free flow of thermal waters were considered impossible under the conditions of pressure assumed to exist there. This view was called a lateral secretion theory, though it differed essentially from that of Sandberger, in that the derivation of the vein minerals was not restricted to the immediate wall rocks (*Nebengesteine*) of the deposits. Indeed, in a later discussion it was characterized as another form of the ascension theory. The circulating waters which had brought in the vein materials were assumed, though not always explicitly, to be of meteoric origin—waters which originally descending from the surface had become heated either in contact with igneous rocks, or by the internal heat of the earth, and gathering up mineral matter in their journey had redeposited it when conditions favored precipitation rather than solution. The natural channels through which these waters would circulate most freely, and which hence were most favorable to ore deposition, were rock fractures produced by dynamic movements in the crust; faults or joints to which Daubrée had given the designation "lithoclases." In no case were these fractures found to be contraction fissures, which Werner and many subsequent writers assumed to be the tpyical vein fissure, disregarding the consideration that contraction fissures could not traverse two distinct bodies of rock. To the joint-like fissures that are confined to a single bed, Whitney had already given the name "gash" veins.

In the Comstock Lode report, Becker had discussed mathematically the mechanics of faulting as applied to vein fissures, and had shown that an important characteristic of faulting on a fissure in solid rock is the tendency of the movement to separate the rock into sheets by subordinate fissures parallel to the main one. From practical observation Emmons had similarly concluded that the faulting movement which produced vein fissures was often distributed on a number of parallel fissures, thus producing a sheeting of the country rock. Where these fissures were sufficiently close together, so that the intermediate sheets of country rock were very thin and had been partially replaced by vein material, a banding would result which might be mistaken for that of the typical vein of incrustation. Where they were farther apart and of approximately equal strength, the mineral filling, instead of being confined to a single fissure, might be distributed on several, thus rendering frequent cross-cutting advisable in their exploitation.

The idea that later formed ore deposits are necessarily the filling of considerable cavities or open spaces in the enclosing rocks has been considerably modified by the important rôle that the process of metasomatic replacement or substitution has been shown to have played in the formation of ore bodies. The idea of replacement had been suggested in the conversion theories of the early speculators and more distinctly expressed by Charpentier. By the geologists of the second period it was comparatively neglected, though in a few cases admitted as a subordinate factor, especially in the formation of deposits in limestone. Even in Posepny's frequently quoted studies of the lead and zinc deposits of Raibl in Carinthia (1873), he admits this mode of formation only for the oxidized ores, considering the sulphide ores to have been deposited in open cavities.

In America, Pumpelly first applied this process to the copper deposits of the Lake Superior region (1871), of which he says: "In at least very many instances, if not in all, the deposition of the copper is the result of a process of displacement of pre-existing minerals."

Leadville and Eureka were the first large mining districts in which it was proved that extensive ore deposits were entirely formed by metasomatic replacement of the enclosing rock, which in these cases was limestone. Later observations showed that this form of deposit was not confined to limestones, and that in fissure vein deposits, even in acid rocks, metasomatic processes had often played an important part in replacing by ore portions of the country rock which, under the old views, might have been regarded as vein filling. The interest and importance of this view were speedily recognized, especially by American geologists and mining engineers, and while still novel, it was doubtless sometimes applied without sufficient proof as an explanation of the formation of certain vein deposits to the exclusion of that of the filling of cavities or interstitial spaces. With the general introduction of the microscope into the study of vein materials, however, a comparatively sure method was provided of distinguishing the results of the two processes. The process of verification has in this case resulted in the establishment of the importance and increasingly wide applicability of the metasomatic theory to the formation of ore deposits of all types.

In the latter part of the decade Irving and Van Hise's studies of the iron deposits of the Lake Superior region had demonstrated that they had been deposited from solution in descending or meteoric waters, whose downward course had been arrested by some impervious basement—sometimes a dike, sometimes a bed in a synclinal basin—and that during this time of stagnation their load of iron oxide had been laid down as a metasomatic replacement of the enclosing rock, a descensionist theory but of essentially modern type.

In 1893 appeared the well known paper, "The Genesis of Ore Deposits," by Posepny, for ten years professor of this branch of the science at the School of Mines in Pribram, Bohemia. Although Posepny's views were by no means universally accepted by geologists, especially in America, all agreed that his work constituted a most valuable contribution to the science by its clear definitions of the questions involved and their masterly scientific discussion. The great majority of ore deposits Posepny considered to be of later origin than the enclosing rocks, even those that are found in stratified rocks in apparent conformity with the bedding. Further, that they have been deposited by precipitation from waters of the deep circulation below the groundwater level. The groundwater he conceived descends by capillarity through rock interstices over large areas to rise again at a few points through open channels under the influence of heat. It derives its mineral matter from the barysphere, or deep region, where the rocks are richer in metallic minerals than near the surface, and subsequently deposits them in open spaces as it ascends. These spaces are either spaces of discission (rock fractures) or spaces of solution, the latter sometimes being formed by ascending thermal waters, even where no previous crack exists.

Fresh as he was from his controversy with Sandberger over the lateral secretion theory, which he had disproved, at least in its application to the Pribram deposits, he was inclined to view with disfavor anything that flavored of lateral secretion; hence, while admitting that the presence of minute quantities of the metals in eruptive rocks leads to the surmise that they had brought the whole series of heavy metals up from the barysphere into the lithosphere or upper crust, he preferred to assume, in the cases which the American geologists had explained as derivation from eruptive rocks in the vicinity of the deposits, that the mineral contents had been brought up by thermal waters directly from the barysphere. Likewise, in the limestone deposits, which their studies show to have been formed by metasomatic replacement, he thought that they must have overlooked some evidence of crustification, and still held to the opinion that such extensive deposits must be mainly the filling of open spaces. Although not explicitly stated, it is evident that he regarded the water of his deep circulation as mainly of meteoric origin.

Of great practical value was the clear idea conveyed to the mind of his readers of the distinction between the oxidized or altered minerals and the original or sulphide minerals of an ore deposit, a distinction previously pointed out, though less emphatically, by Emmons* and others.

In the same year appeared the first of a series of important articles on the formation of ore deposits by the Norwegian geologist, J. H. L. Vogt, in which, as opposed to Posepny's views, so much more importance is given to igneous agencies that their different standpoints recall the antagonisms of the old Neptunist and Plutonic schools. The petrographic studies of Vogt and Brögger had disclosed in basic dikes a tendency of the heavier minerals to concentrate near the borders. Following out the suggestion offered by this observation, Vogt had proved by field study that certain titaniferous iron ores were actual segregations in the eruptive magma previous to its final consolidation. Based on petrographic studies made by Brögger and himself, and personal observations on ore deposits, principally in Norway, Vogt defined two methods of formation of ore deposits as the direct result of igneous action:

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* Colorado Scientific Society, vol. ii, pt. ii, 1886, p. 99.

1. By magmatic segregation.
2. By eruptive after-action or pneumatolysis (a term first used by Bunsen to describe the combined action of gases and water).

In the first class (of admittedly infrequent occurrence) are titaniferous iron ores, chromite, and other metallic segregations in basic eruptive rocks. In the second class, commencing with tin and apatite veins, he included, as time went on, increasingly numerous types of deposits. This was in one sense a revival of de Beaumont's theories, but the modern standpoint differed, in that the existence of a liquid molten interior of the earth had been disproved by terrestrial physicists. Vogt held that as no communication could be established between ore deposits and a heavy interior, they must have been derived from a crust, say, ten, twenty-five, or fifty kilometers in thickness, and in great measure the result of eruptive processes within that crust.

Emmons (in 1893) acknowledged the importance of the magmatic concentrations of metals in eruptive rock, but thought that in most cases such accumulations must have been further concentrated in order to produce economically valuable ore deposits.

During the second decade the influence of Posepny's paper was felt in an increased adherence among outside geologists and mining engineers to the ascension theory. Vogt's views received less attention in this country, because for a long time no ore deposits were studied to which they were found to be applicable. The first case was that of the titaniferous magnetites of the Adirondacks studied by Kemp, who published his results in 1898.

The year 1900 was rendered important in the progress of theoretical views on ore deposition by the simultaneous appearance of "Principles controlling deposition of ores," by Van Hise; "Secondary enrichment," by Emmons and Weed, and "Metasomatic processes," by Lindgren, and by the discussions which they prompted.

Van Hise's article was a broad, philosophic treatment, based on experimental data, of the whole question of underground circulation as bearing on ore deposition. It would be impracticable to give here any complete abstract of his paper, which is probably familiar to most of you, and only a brief statement of such points as bear on the general processes heretofore alluded to will be attempted. His discussion is practically confined to ore bodies deposited from aqueous solutions, which, he considers, embrace the larger proportion of workable deposits, and he holds that the waters from which these deposits have been made are chiefly of meteoric origin. Their circulation is in part descending, in part lateral moving, and in part ascending, and during each of these movements they may take up or deposit metallic minerals according as conditions favor either action. This circulation takes place in openings in rocks, mostly produced by fracture, and hence is confined to the outer portion of the crust, which he has defined as a zone of fracture as distinguished from a deeper zone, that of flowage, where, under accumulated pressure, deformation produces no macroscopic openings. Its general tendency is to concentrate from the small openings into larger or trunk channels. The deposits from these waters are distinguished as concentrations (1) from ascending waters alone, (2) from descending waters alone, and (3) first from ascending and second from descending waters. In prevailing composition the first class are sulphides, tellurides, etcetera; the second oxides or oxide salts, while the third are chiefly the one or the other, according as they were formed above or below the ground water level.

Emmons and Weed, coming to the subject from a different but somewhat narrower standpoint—that of a practical field study, extending over several years—explained the frequent occurrence of bonanzas, or exceptionally rich portions of deposits just below the oxidized zone or ground water level, as the result of leaching by surface waters of the upper portions of these deposits and their redeposition as sulphides in contact with preexisting metallic sulphides (especially pyrite) in the zone below. Through similar processes of chemical reasoning and with a similar disregard of Posepny's assumption that the ground water level forms an effective barrier separating the action of the surface or vadose waters from that of the deep circulation, all three arrived at the same general conclusion with regard to the continuance of rich ore in depth, a question which has occupied the attention of geologists and miners since the days of Werner. This conclusion was that in most ore deposits a deeper region exists beyond the influence of surface waters in which the ore is of comparatively low and uniform grade. Van Hise even went so far as to say that in depth all deposits would become low grade pyritic ores, and that all veins would eventually wedge out.

De Launay, in his generalizations on Mexican deposits, had already recognized three zones: (1) an upper oxidized zone, (2) a middle zone of rich sulphides, and (3) a lower zone of low grade sulphides. He assumed the enrichment of the middle zone had been by descending waters, but placed it above the groundwater or hydrostatic level, which in many veins had probably been displaced since their original formation.

In his article "On metasomatic processes in fissure veins," Lindgren placed this theory for the first time on a scientific basis of chemical and microscopical study, and by a classification of veins according to the predominant metasomatic mineral or process involved, he made its application much clearer to the student and observer. In his closing remarks he suggested that of late sufficient attention had not been given to the French theory of emanations from eruptive magmas, and that in the case of metals with low critical temperature they may have first been carried up under pneumatolytic conditions and with the aid of mineralizers while still above the critical temperature, until they reached the zone of circulating atmospheric waters.

His paper "On contact deposits" (1901), following out this suggestion, served a useful genetic purpose by calling attention to and clearly defining a group of deposits for which a pneumatolytic origin would readily be admitted, but of which no important examples had yet been studied in America. The term "contact deposits," which had hitherto been loosely applied to all deposits, without regard to origin, which happened to lie near the contact of any two bodies of rock, was restricted by his definition to those occurring near the contact of igneous intrusives with calcareous beds. They are characterized by irregularity of form, the association of iron oxide and sulphides of the metals with various lime silicates, generally called "contact" minerals because they are found to be the result of contact metamorphism. Typical developments of these contact minerals near Christiania in Norway, in the Banat in Servia, in Tyrol, Italy, and elsewhere had been the subject of repeated study and discussion among European geologists since the middle of the century, but the metallic deposits connected with them being generally of subordinate economic importance had, up to the time of Vogt, not been considered worthy of a distinct place in the classification of ore deposits.

The importance of pneumatolysis in forming ore deposits was emphasized by the discovery on this continent,soon after the publication of Lindgren's paper, of a number of economically important deposits, especially of copper, which would come within his definition of contact deposits.

From a more theoretical point of view the contemporaneous paper of Kemp, "The rôle of igneous rocks in the formation of veins," presented a more decided opposition to the view so emphatically voiced by Van Hise, that the majority of our ore deposits have been formed by precipitation from circulating waters of original meteoric origin. In this Kemp maintains that groundwater circulation is not sufficient to account for the majority of ore deposits, but that igneous rocks must have furnished not only their metallic contents, but a large, if not predominating, proportion of the waters which brought them into their present position.

The controversy which had thus arisen as to the relative importance in the formation of ore deposits of waters of meteoric or of igneous origin has more recently received a further impulse in the discussions provoked by the presentation of proposed genetic classifications of ore deposits by W. H. Weed and J. E. Spurr. These geologists took an even more advanced position than Vogt in regard to the direct influence of igneous agencies in the formation of ore deposits, adding siliceous segregations to his class of magmatic differentiation products and very greatly enlarging the scope of his pneumatolytic class. The influence of these new views is already seen in the current literature on ore deposits, especially in articles where the author, though not in possession of full data, still feels it incumbent upon him to present some tentative hypothesis of origin for the deposits which he is describing.

Results achieved

The wide divergence of views shown by these discussions to be held by recognized authorities on the subject might lead one to conclude that we are as far as ever from a universal agreement on accepted theories. A more deliberate consideration of the progress of investigation and verification during this last period, which has been but too briefly and imperfectly set forth in the preceding pages, will show, however, that the advance in this direction has been real and permanent as far as regards the later stages of ore formation, which are more susceptible of actual proof, and that the disagreement lies rather with the ultimate or more theoretical sources of derivation, which must always remain to some extent matters of opinion.

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DOMES AND DOME STRUCTURE OF THE HIGH SIERRA

BY G. K. GILBERT

(Presented to the Society January 1, 1904)

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GENERAL CHARACTER OF THE DOMES

In the granite areas of the Sierra Nevada are many hills and other summits having the form of domes. A few of the domes are symmetric, with approximately circular or oval bases, but the majority are somewhat one-sided or irregular. Associated with these domelike forms are closely related structures. The granite is divided into curved plates or sheets which wrap around the topographic forms. The removal of one discloses another, and the domes seem at the surface to be composed, like an onion, of enwrapping layers.

THEORIES OF RELATION BETWEEN STRUCTURE AND FORM

In explanation of these peculiar forms and structures two general theories have been advanced.* According to one theory the separation of the granite into curved plates is an original structure, antedating the sculpture of the country and determining the peculiarities of form.

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*H. W. Turner gives a digest of opinions, with references, in Proc. Cal. Acad. Sci., 3d ser., Geology, vol. 1, pp. 312-315. To his enumeration may be added Muir (Am. Assoc. Adv. Sci. Proc., vol. 23, pp. 61-62) and Le Conte (Elements of Geology, 4th ed., pp. 283-284), both on the side of original structure.

According to the other theory the structure originated subsequently to the form, and was caused by some reaction from the surface. Visiting the Sierra in the summer of 1903, I had these two theories in mind, and sought for characters by which they might be tested.

The dome structure appears not to extend downward and inward indefinitely, but to be limited to a somewhat shallow zone. The opportunities for observing this fact of distribution are not numerous, and, so far as I am aware, are found only on what are called half domes—that is, domes that have been pared away on one side so as to exhibit the structure in section. The Half dome at the head of Yosemite valley, which has been described by several writers, has been undercut in the development of the glacial trough of Tenaya creek, so that its northwestern part has fallen away. The curved plates are there seen (figure 1) to occupy a very moderate depth, probably not more than 50 feet, while beneath them the rock is massive, except as vertical shear planes or joints have developed parallel to the flat face. In another instance the estimated depth of the zone of dome structure is about the same, and in a third instance about 100 feet. This downward limitation of the zone appears to me favorable to the second theory. If the structure were original, one would expect to find it continuing indefinitely downward and inward.

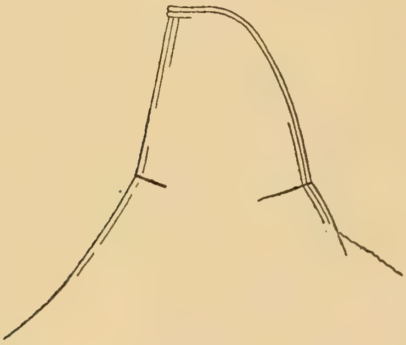


Figure 1.—*Section of the Half Dome, showing the relation of the dome structure to the surface and to joints.*

The section is at right angles to the side shown in plate 2.

The structure is not restricted to domes. In some districts the walls of canyons, the sides of ridges, and the bottoms of trough valleys are characterized by partings approximately parallel to the surface. (See plate 3, figures 1 and 2.) These partings are not ordinary joints, but are distinguished by curvature, and their forms of curvature are always adjusted to the general shapes of the topography. In the last respect they differ greatly from the structures produced by folding of strata. The curves of folded strata are diversely related to topographic features. A syncline may be found in a valley or on a hilltop, and an anticline may have either of these positions; but in dome structure each anticline coincides with a summit and each syncline with a valley. If the dome structure were original, we should expect that it would often be traversed discordantly by superposed drainage and dissection, and the fact of its accordance with features of dissection is therefore unfavorable to the theory that it is an original structure.

Where the granite is divided by a solitary joint into distinct masses, the dome structure of each mass is independent of the structure developed in its neighbor (figure 1). The curves of the dome structure do not cross the joint plane, and are thus shown to be newer than the joint. This phenomenon is not favorable to the view that the structure is original.

These considerations, as they were developed gradually in the field, led me to abandon altogether the hypothesis that the structure was developed either in the original constitution of the granite or at some early stage in its history, and to adopt the alternative view that it followed the production of the principal topographic features and was in some way conditioned by the surface forms.

Relation of Dome Structure to Plane Jointing

The dome structure appears to have been developed only in massive rock; that is to say, it is not found in rock which is divided by systems of parallel plane joints. Through large areas the granite is divided by such joint systems into angular blocks (plate 4, figure 1), and in these areas the peculiar domes do not appear. I thought at one time that the two types of partings might be correlated with certain rock types, but this tentative generalization was afterward completely disproved. There are at least three prominent and broadly exposed types of granite in the Sierra which exhibit dome structure, and each of these is also characterized in some different locality by plane joints. It is easy to understand that the existence of either system of partings within the rock might, by facilitating the relief of strain, prevent the development of the other system, so that their mutual exclusiveness gives no indication of their relative age. But there is independent reason for assigning a greater age to the plane joint systems. The dome structure, being conditioned by surface forms, is in each locality more recent than the topographic features; but the topographic sculpture is superposed on the systems of plane joints. Minor details of form show the influence of joint structure, but features of the rank of hill and valley are notably independent, their trends making all angles with the strikes of joint systems.

Joints and other division planes are aids to erosion, whether the process be subaerial or glacial. When in ordinary jointing several sets of division planes intersect and the rock is separated into blocks, weathering and transportation are both facilitated. In dome structure there is but a single set of division planes, and the broad rock plates are almost as resistant as a continuous mass. It results that the granite masses divided only by dome structure tend to survive general degradation, and often to stand forth as prominent hills.

THE QUESTION OF CAUSE

In the effort to pass from the general phenomena of dome structure to its cause, I have found instruction in a comparison of the disrupting effects of expansion and contraction. When a forest fire sweeps over a rocky hillside the surfaces of rocks are rapidly heated and thereby expanded. The result is a sort of exfoliation. Flakes of rock, broad in comparison with their thickness, break loose and fall away (plate 4, figure 2). Thus the effect of surface expansion is to develop partings approximately parallel to the original exterior. The effect of contraction is illustrated by the cooling of a lava stream or dike. The cooling and contraction begin at the surface, and there develop a plexus of cracks, which are propagated downward or inward as cooling proceeds. These cracks are normal to the surface, and they separate the rock into normal columns. Comparing dome structure with these familiar types, it seems evident that it should be ascribed to expansion rather than to contraction, and we are led to inquire what natural process or processes may have expanded the Sierra granite at the surface.

Heating is naturally the first to suggest itself. Diurnal and annual changes of temperature may be dismissed at once, because their influence penetrates but a small distance. Secular changes penetrate farther, and may be quantitatively adequate. Secular warming after glaciation may have been a *vera causa*, but its discussion is complicated by the fact that the dome structure, or at least its principal part, antedated a large amount of glacial erosion. If the structure originated with Pleistocene climatic changes, the changes must have pertained to an early epoch of glaciation.

A second process developing expansive force is weathering, and here again future investigation may discover a true cause; but to cursory and inexpert observation the granites of the Sierra in the glaciated district appear to be unaltered.

A third process—one as to which we have no direct knowledge—is dilatation from unloading. When the granite came into existence by the cooling of the parent magma it was buried under a deep cover of older rock. Because of that cover it was subject to compressive stress, and that compressive stress was of course balanced by internal expansive stress competent to cause actual expansion if the external pressure were removed. As in course of time the load was in fact gradually removed, the compressive stress was diminished and the expansive stress became operative. *Pari passu* with this release of expansive stress there was cooling, and the effect of the cooling was to diminish expansive stress; and the result may have been complicated by other stress factors. So long as the pressure of superjacent material was great, the equilibrium of stresses was approximately adjusted by flowage; but as the descending surface of degradation approached the granite, flowage diminished, and it ultimately ceased. The final adjustment was by change of volume, the change being contraction if lowering of temperature was a more important factor than relief from load, and expansion if relief from load was the more important factor. In the latter case (which I regard as the more probable) the parts of the granite successively exposed at the surface were in a condition of potential expansion, or tensile strain, and that strain would be relieved by the separation of layers through the development of division planes approximately parallel to the surface.

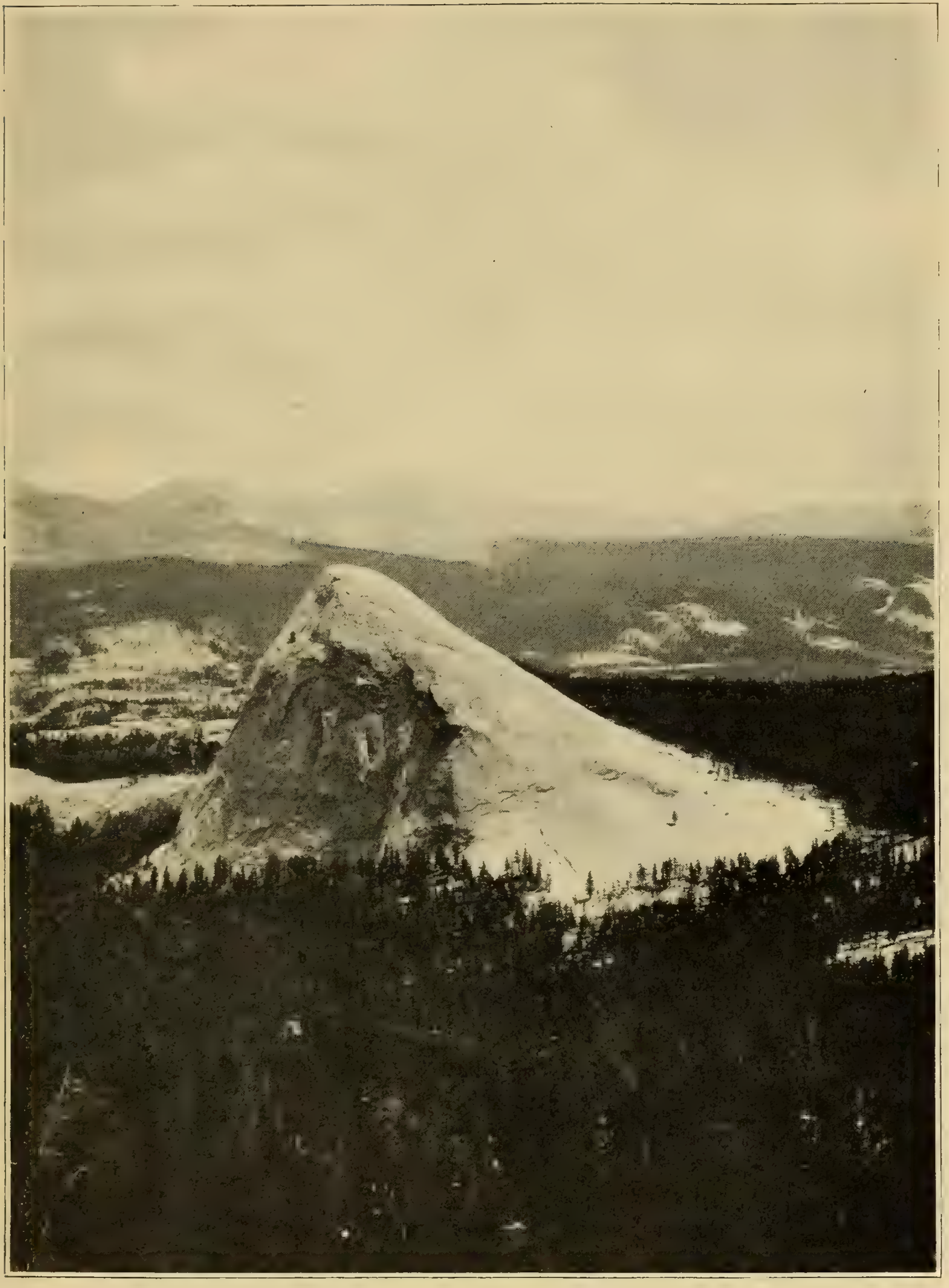
While it is possible that all these processes are concerned in the production of the structure, I regard it as more probable that some one cause is dominant. The data at hand seem to me not to warrant a confident selection from the three suggested, but if the truth lies among them, there should be little difficulty in obtaining additional facts of crucial character. Certain domes, some of which I saw at a distance, are supposed to be outside the area of Pleistocene glaciation. If they exhibit the characteristic structure, and are really extraglacial, their characters can not plausibly be ascribed to secular changes of climate. It should be possible to determine the relation of weathering to the structure by petrographic study of outer and inner layers at such a locality as that shown in plate 3, figure 1, where glacial erosion has exposed a fresh section.

EXPLANATION OF ROUNDING

The view in plate 3, figure 1, was selected as an illustration of dome structure because the plates and partings of the structure are there shown in natural section. In the making of that section the dominant erosional process was glacial attrition or grinding. While this process has been of great importance in the sculpture of the higher parts of the Sierra, it is probably second in rank to glacial plucking or quarrying; and glacial degradation as a whole has been small in comparison with subaerial degradation. In glacial plucking and in most phases of subaerial erosion the most active attack on rock traversed by dome structure is by way of the partings, and the broad outer faces of the granite plates are comparatively unaffected. The removal of the rock is essentially through a process of peeling. One layer at a time is carried away, and the surface at each stage coincides approximately with one of the partings.

Whatever the cause of the dilatation producing the partings, they are formed in succession from without inward. For each one the determining strains are themselves conditioned not only by the form of the outer surface, but by the form of the last made parting. Parallelism is not perfect but approximate, and the departures from strict parallelism are of such nature as to reduce or omit angles and other features of irregularity. The inner partings reflect only the general features of the external sculpture. As peeling progresses and the zone of competent strain moves inward, the outer surfaces are successively more and more simple in contour, and the newly developed partings are endowed with still greater simplicity.

Opposed to the rounding process is corrasion. The attrition of a detritus-armed stream or glacier saws through the rock plates with little regard for the presence or absence of partings. By so doing it creates discordant elements of topography and modifies the conditions under which the expansive strains are developed. In the Sierra the effects of glacial corrasion are at present conspicuous. By the corrasion of the Tenaya trough the base of Half dome was sapped, so that a part was sheared off by gravity, producing a vertical flat face (figure 1), in which the structureless nucleus was exposed. In this face the "dome structure" was developed, but, being conditioned by a plane outer surface, the new partings are plane (except at the edges), and thus simulate ordinary plane joints.



FAIRVIEW DOME

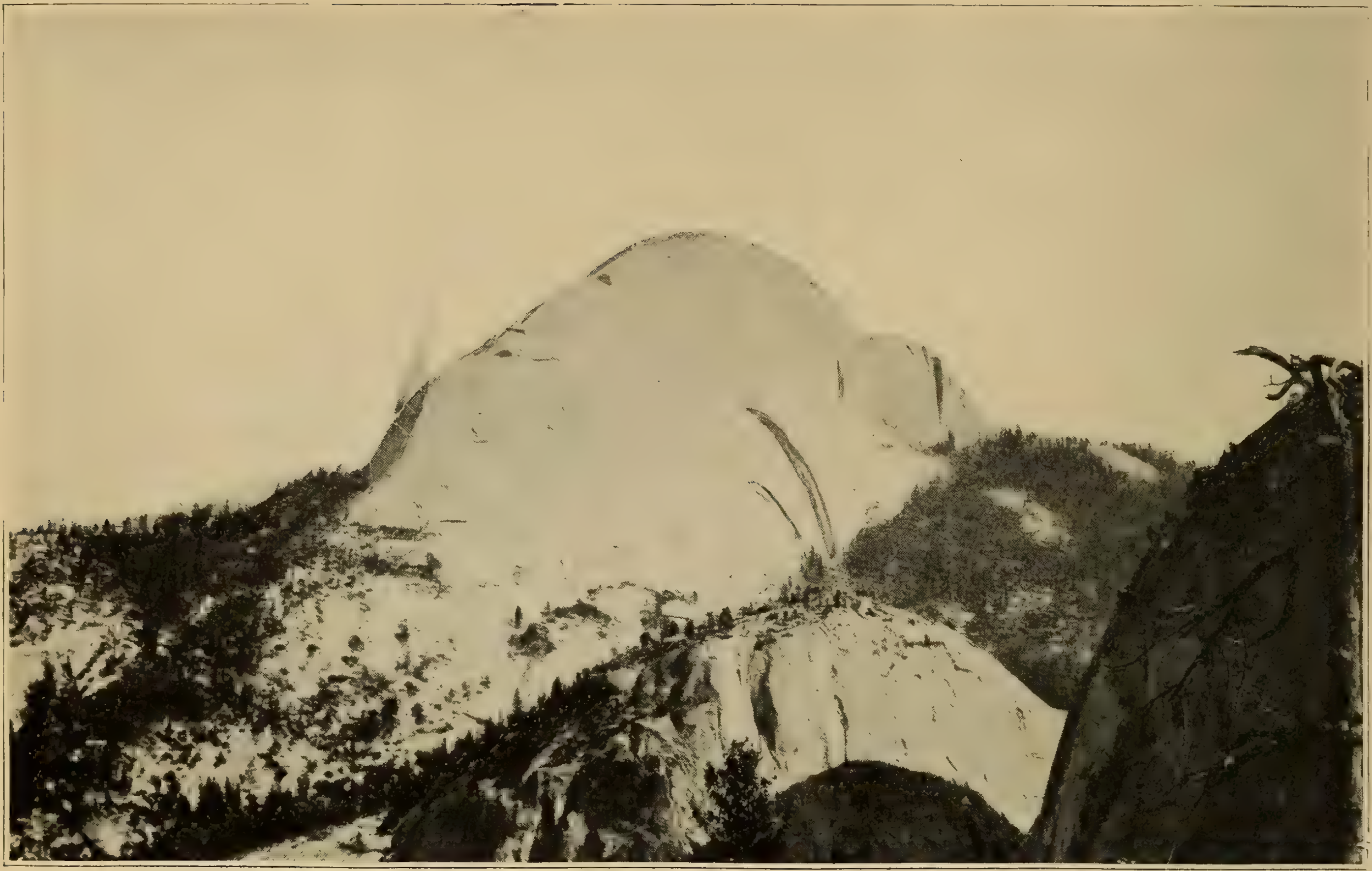


FIGURE 1.—HALF DOME AT EAST END OF YOSEMITE VALLEY, SEEN FROM THE SOUTH

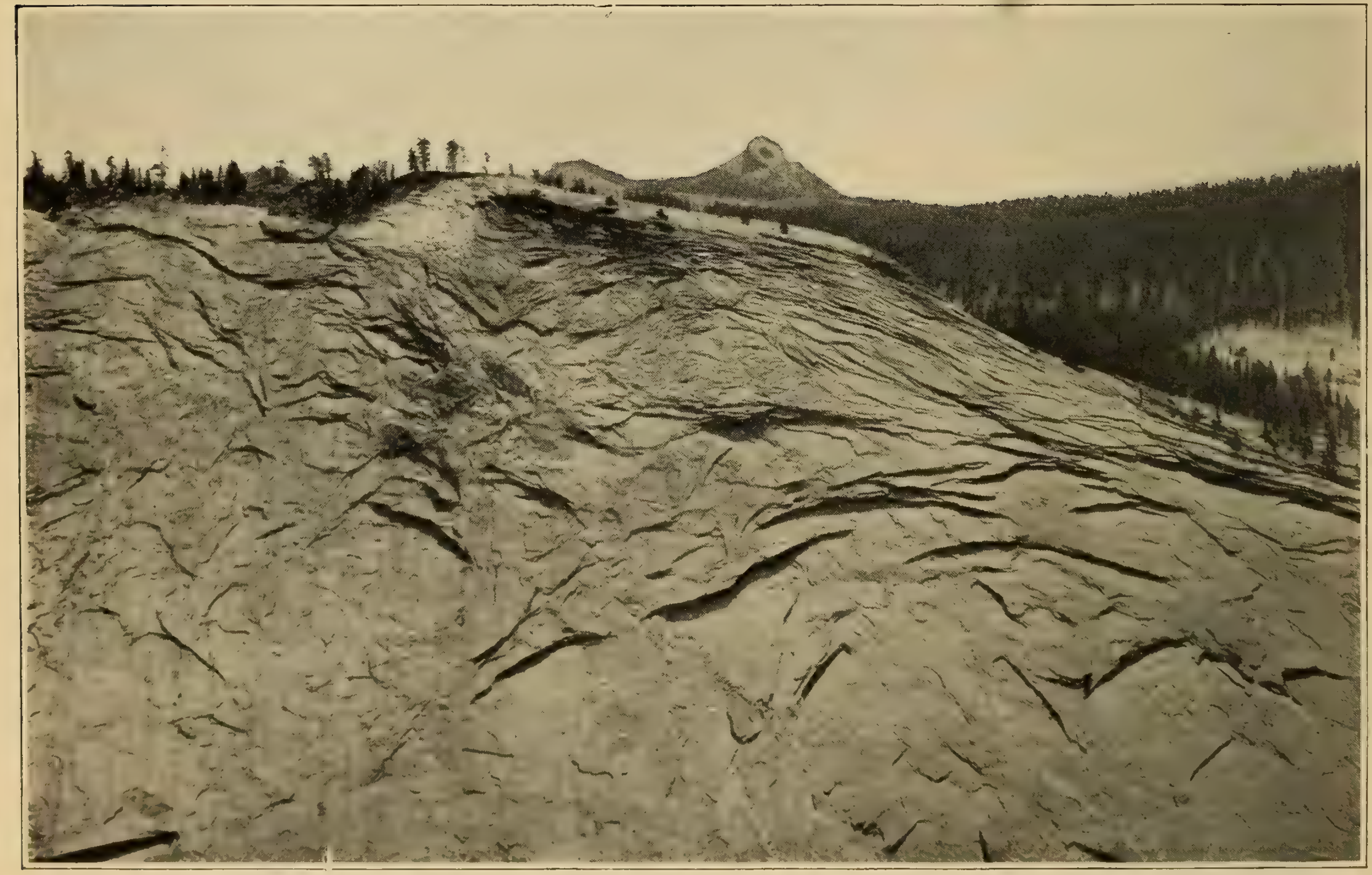


FIGURE 2.—PART OF THE SOUTHEAST WALL OF LITTLE YOSEMITE VALLEY, SHOWING DOME STRUCTURE

DOME STRUCTURE IN THE YOSEMITE REGION

EXPLANATION OF PLATES

PLATE 1.—*Fairview Dome*

This dome, sometimes called Tuolumne monument, is in the Sierra Nevada, west of Tuolumne meadows. In common with the surrounding country, it is of granite. It stands at the edge of a plateau, its summit being 800 feet above one base and 1,300 feet above the other; it is not above timberline, but is bare of trees, because in the absence of joints they get no foothold. Pleistocene ice covered it, flowing from right to left and from distance to foreground.

PLATE 2.—*Dome Structure in the Yosemite Region*

FIGURE 1.—Half Dome, at east end of Yosemite Valley, seen from the south; from a photograph by C. D. Walcott.

The view shows the convex side of the dome, in which the structure closely parallels the surface. The height above the nearer base is about 1,500 feet; above the farther base at right 900 feet. The dome was covered by Pleistocene ice, which moved from the right and from the distance. The surface is treeless, because devoid of joints. No rock but granite is visible in the view.

The text contains a cross-profile of the dome.

FIGURE 2.—Part of the southeast wall of Little Yosemite Valley, showing dome structure.

The rock is granite. The valley is deeply incised in a plateau of relatively mature topography. Pleistocene ice covered everything shown in the view except the distant crest, but the glacial degradation of the upland was slight.

In the upper parts of the cliff the dome structure parallels the surfaces of the upland topography; lower down it parallels the cliff face.

PLATE 3.—*Dome Structure near Emerick Lake*

FIGURE 1.—Hill southeast of Emerick Lake, Upper Merced Basin, Sierra Nevada.

The hill, which is about 250 feet high, is the terminal and culminating point of a long ridge of granite. The dome structure in the ridge is anticlinal, changing in the hill to the inverted canoe form. At the extreme right the convex or anticlinal curvature is seen to merge into a concave or synclinal curvature, better shown in figure 2. The hill was deeply buried by a glacier moving from left to right. Glacial erosion made the rock basin occupied by the lake and excavated the hillside so as to expose the dome structure in partial section.

FIGURE 2.—A Syncline in dome structure.

Emerick lake (figure 1) lies out of sight, just beyond the granite slope at right. Its outlet, crossing the sill without notable incision, descends to the foreground at left. Structure and topographic configuration are in harmony. A syncline pitches toward the foreground and also (slightly) toward the lake. At the lip of the lake basin the cross-section is synclinal and the longitudinal section anticlinal.

PLATE 4.—*Joint Structure and Fire Spalling*

FIGURE 1.—Jointed granite in Kuna Crest, Sierra Nevada.

The granite is traversed by four systems of parallel plane joints. The cliff is at the head of a glacial cirque, and the sloping plain above it belongs to preglacial topography. The general forms of cirque and plain are independent of the attitudes of the joint systems. Compare with plate 3 and observe the contrast between joint structure and dome structure.

FIGURE 2.—Granite boulder from which spalls or flakes have been riven by the heat of forest or meadow fires.

The spall at the left, still standing in position, illustrates the approximate parallelism of fractures thus produced to the exterior surface. Probably in this case the strong heating was at the side and local—as the heating would be, for example, if the log at the right should be burned—and the small size of the spall was determined by the localization of the heat.

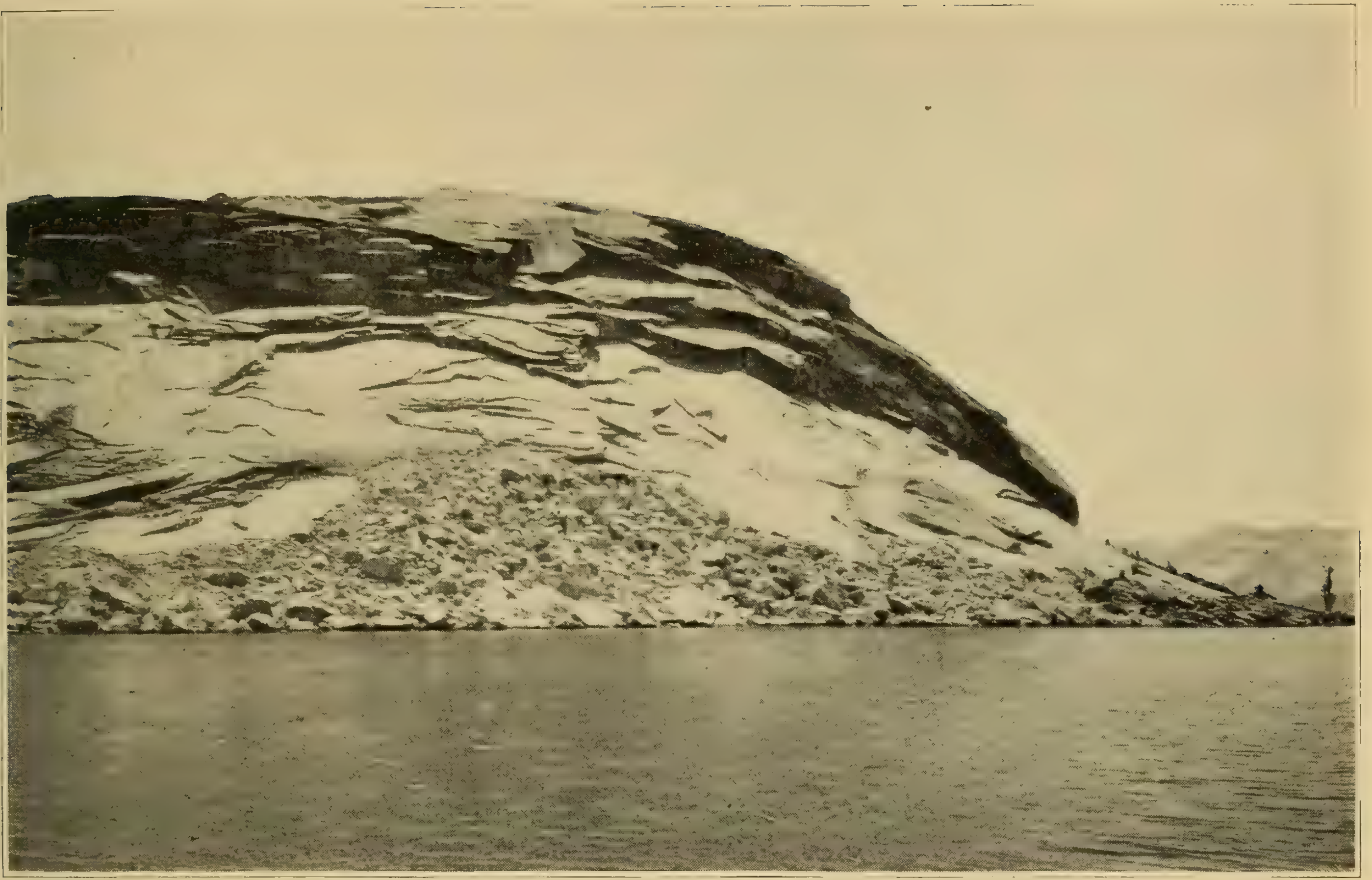


Figure 1.—Hill Southeast of Emerick Lake, Upper Merced Basin, Sierra Nevada

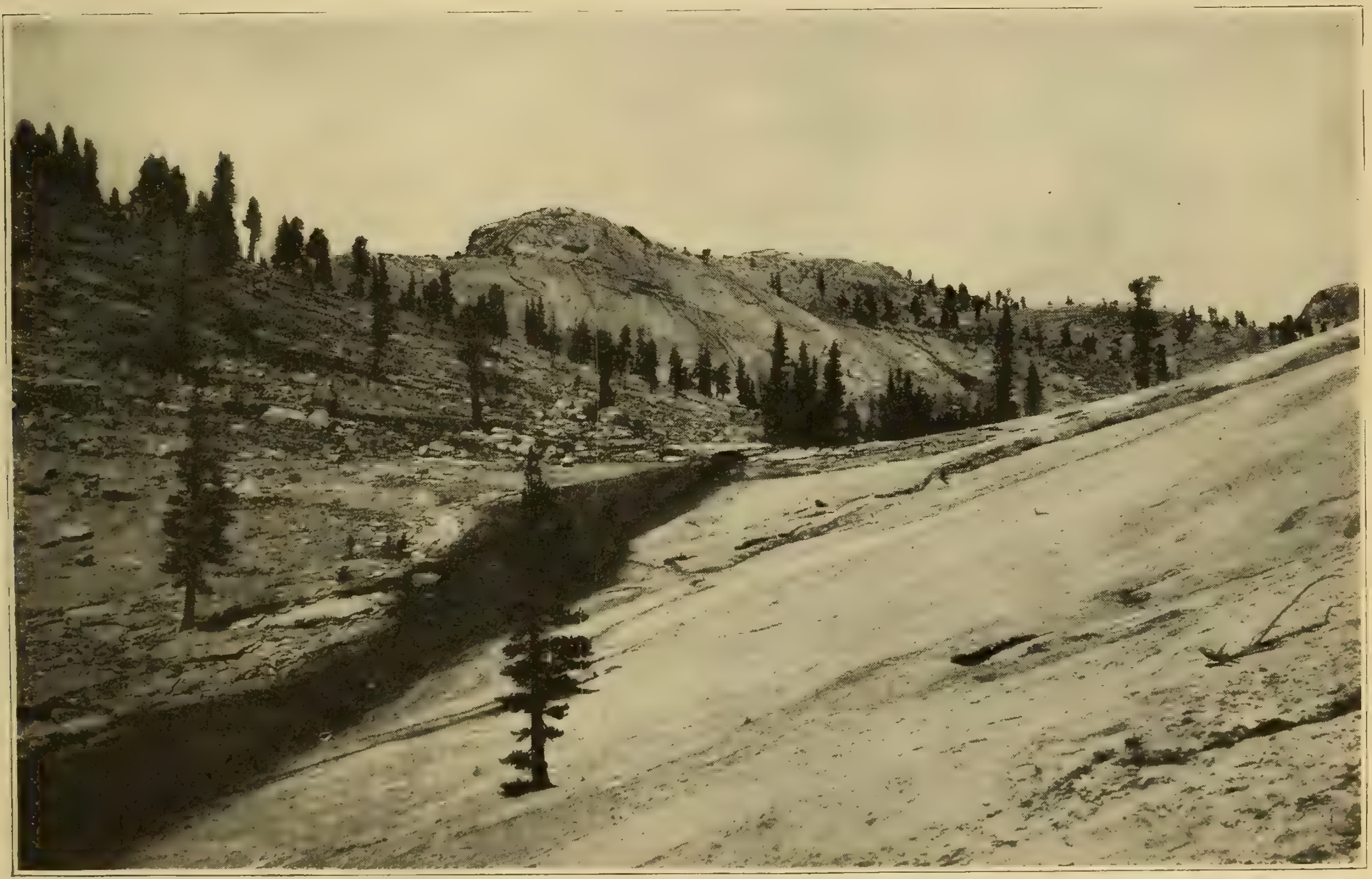


Figure 2.—A Syncline in Dome Structure

DOME STRUCTURE NEAR EMERICK LAKE

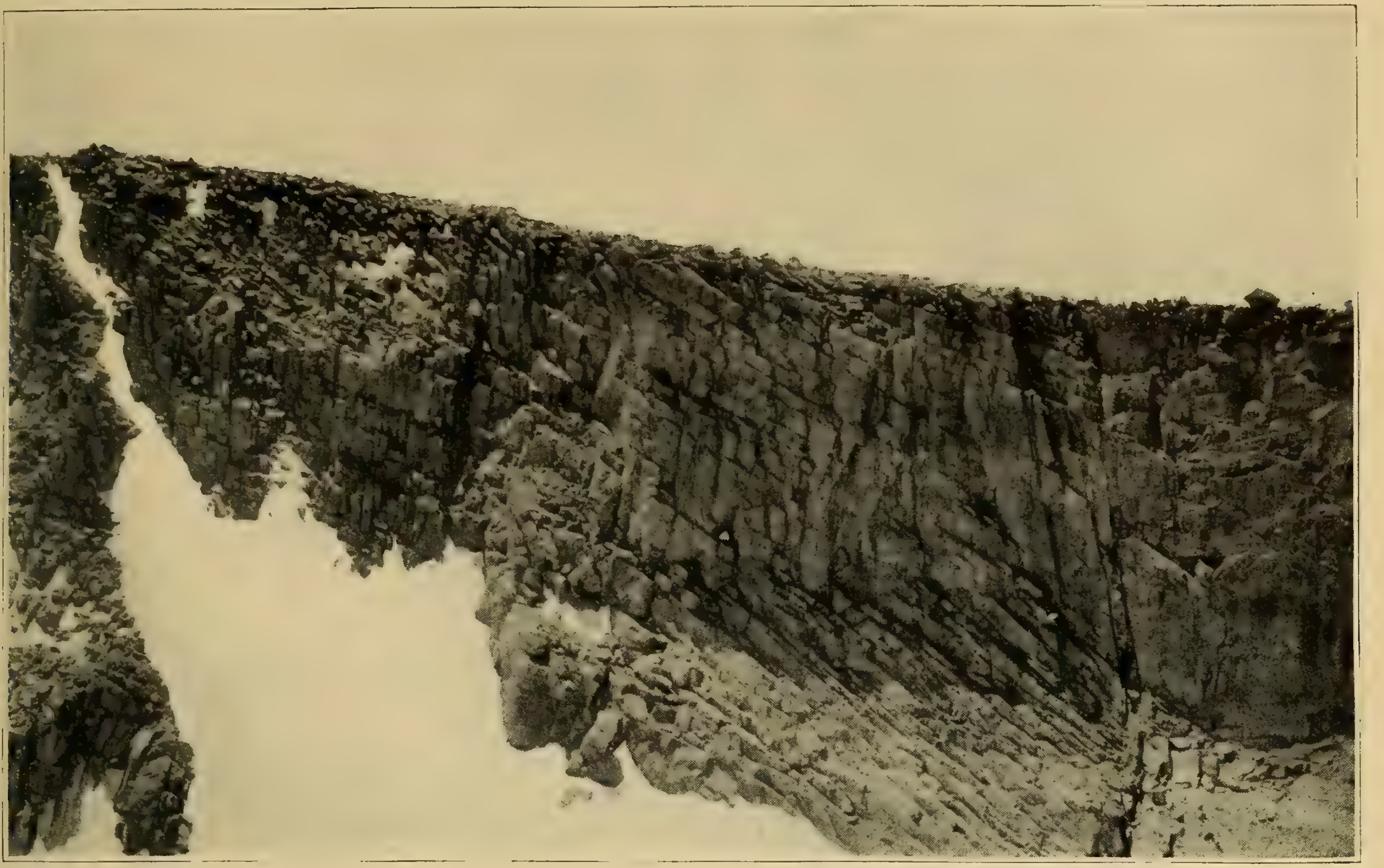


FIGURE 1.—JOINTED GRANITE IN KUNA CREST, SIERRA NEVADA

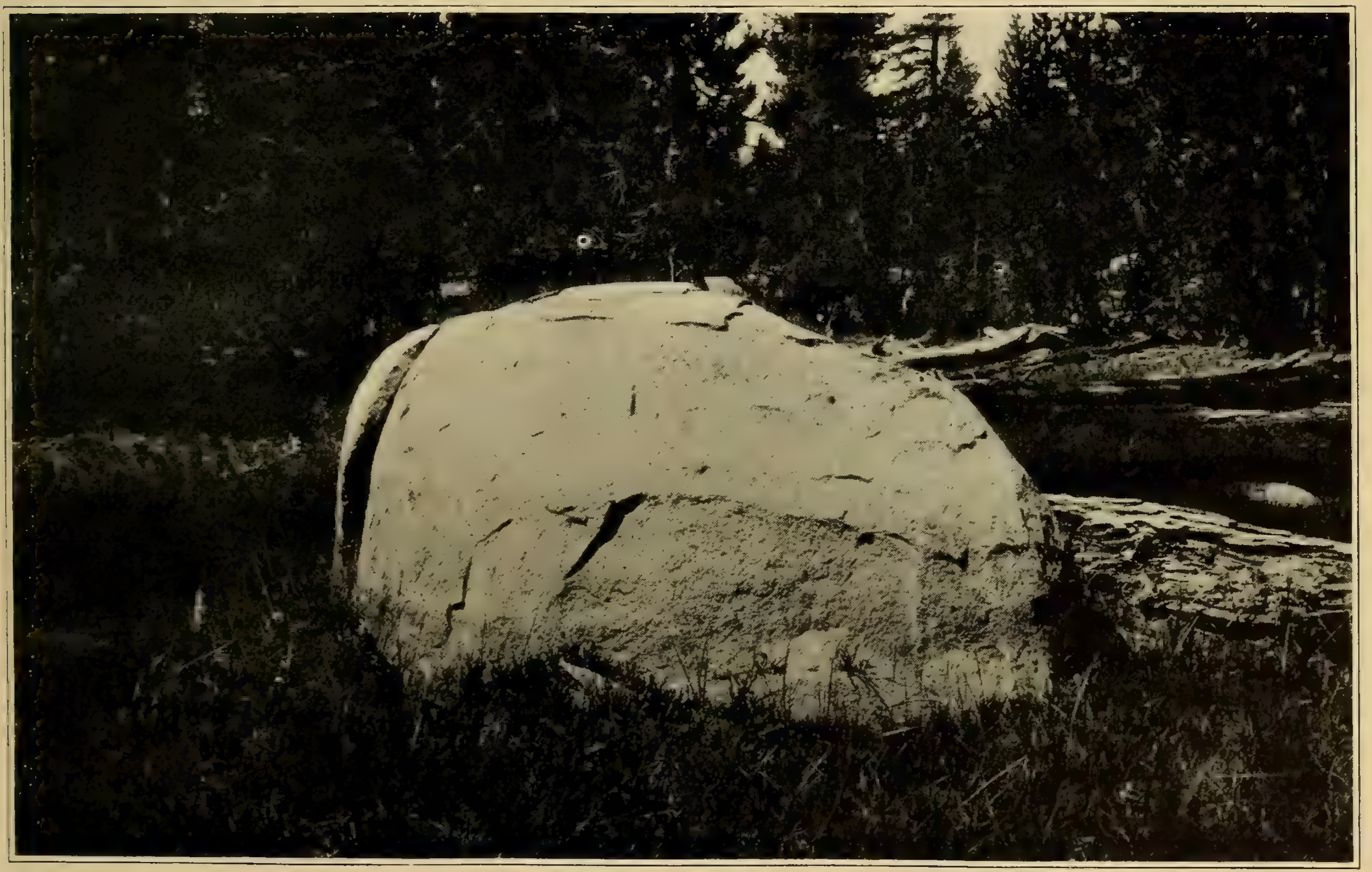


FIGURE 2.—GRANITE BOULDER FROM WHICH SPALLS OR FLAKES HAVE BEEN RIVEN BY THE HEAT OF FOREST OR MEADOW FIRES

JOINT STRUCTURE AND FIRE SPALLING

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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CARBONIFEROUS OF THE APPALACHIAN BASIN

BY JOHN J. STEVENSON

(Presented before the Society January 1, 1904)

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INTRODUCTION

In a former memoir* the writer described the Lower Carboniferous or Mississippian of the Appalachian basin. In this the effort will be to describe the lowest formation of the Coal Measures or Pennsylvanian of the same basin.

The Coal Measures were studied in detail first in the Virginias and Pennsylvania by Professors William B. and Henry D. Rogers, who divided them into five groups, numbered XII, XIII, XIV, XV, and XVI, and afterwards named

XVI. Upper barren group.
XV. Upper coal group.
XIV. Lower barren group.
XIII. Lower coal group.
XII. Seral conglomerate.

This grouping, based originally on somewhat arbitrary grounds, proved so convenient that it was accepted by most of those who have written on the northern portion of the Appalachian basin. In accordance with later usages, geographical terms were introduced by the Pennsylvania geologists. Those which have the priority are

Dunkard of I. C. White,
Monongahela of H. D. Rogers,
Conemaugh of Franklin Platt,
Allegheny of J. P. Lesley,
Pottsville of J. P. Lesley,

these being equivalent to the divisions as made by the brothers Rogers.

The literature is extensive, as the Coal Measures of the Appalachian basin early attracted investigation; but the limits of this study make necessary the use of only the later studies, which superseded those made by the older geologists under less favorable conditions.

POTTSVILLE OF LESLEY: SERAL CONGLOMERATE OF ROGERS

NOMENCLATURE

The Seral conglomerate of Rogers is between the Mauch Chunk red shales below and the lowest bed of the Allegheny above. The formation exhibited at Pottsville in the Southern Anthracite field, with the Buck Mountain coal bed as the roof, was taken by J. P. Lesley as equivalent to Seral conglomerate, to which he gave the name Pottsville. This term was applied in the Bituminous fields, and the typical section obtained by Doctor I. C. White in northwestern Pennsylvania was recognized by Professor Lesley as equivalent to that at Pottsville. Doctor White's section is

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* Part I, "Lower Carboniferous of the Appalachian Basin," was published in this Bulletin, volume 14, pp. 15-96. The writer desires to acknowledge his great indebtedness to Dr I. C. White and Mr David White, who have granted without reserve all his requests for information. It must be understood that this statement does not commit either of those observers in favor of the writer's conclusions.

Homewood sandstone ;
Tionesta coal bed ;
Mercer group, with two or more *coal beds* and two limestones ;
Upper Connoquenessing sandstone ;
Quakertown shales and *coal bed ;*
Lower Connoquenessing sandstone ;
Sharon shales and *coal beds ;*
Sharon sandstone—

a succession which is distinct in a great part of the basin.

THE ANTHRACITE STRIP

Location and extent of the fields.—In the study of the Pottsville formation the same general course will be followed as in the former memoir, but the complexity of conditions in Virginia and West Virginia renders a slight modification necessary, and that area will be examined last of all. The study begins, then, in Pennsylvania with the Anthracite strip.

The Anthracite fields are three in number, occupying small areas in northeastern Pennsylvania. The Southern, the largest, beginning at a little way from the Susquehanna river, extends eastwardly for about 70 miles. Owing to the development of a strong anticline, it forks at the west, and the whole of the Coal Measures passes out in each canoe before the Susquehanna is reached ; but the synclinal basins have been traced far beyond that river by Professor Claypole, who found that the northerly basin, curving toward the south, continues through Perry and Cumberland counties into Franklin, where it is distinct until within 40 miles of the Maryland line, or to about the latitude of the Broad Top coal field, in Bedford and adjacent counties. This Southern field lies wholly east or southeast from North or Tuscarora mountain and is within the Great valley.

The Middle field, divided into the western Middle and the eastern Middle, lies next toward the north. The western Middle is practically in contact with the Southern at the most northerly point of the latter, and extends rudely parallel to it for upward of 30 miles, but reaches hardly so far westward. The eastern Middle, farther north, overlaps the western for a few miles at its west extremity and extends east almost as far as does the Southern. It is made up of a number of small detached basins, some of which, in spite of limited extent, possess great economic importance.

The Northern field, wholly isolated, its southwestward point being at least 12 miles from the nearest portion of the eastern Middle, is a curved canoe, the curve being due to change in direction of the Appalachian strike, so that toward its northeasterly end the trend is almost east-northeast.

The structure is complex in these fields. At the western end of the Southern field the folds are normal and the dips are comparatively gentle, 30 degrees on the northerly and 20 on the southerly side; but eastwardly the disturbance increases; within 15 miles on the southerly side the folds are overturned, the beds are shown with southerly dips of 70 to 80 degrees, and an important fault appears near the origin of the basins. Thence the complication becomes more marked; overturned folds as well as faults are of common occurrence, and the consequent pinching and crushing of the coals renders mining problems serious. This close folding is especially notable along the southern border of the field, and the folds become more open toward the northern border.* The conditions in the Middle fields are scarcely less complicated than in the Southern, but in the Northern, overturned folds, though not unknown, are less frequent and the disturbances are less severe.†

Southern field.—The thickness of Pottsville in the southern prong of this field has been estimated at from 1,200 to possibly 1,700 feet, accurate measurements being out of the question and the calculations being made from cross-sections which in most cases are incomplete. The upper half of the formation is very massive, contrasting in this respect with the lower half. The northerly prong shows a thickness of 1,400 to 1,475 feet, the upper 600 to 700 feet, being a coarse massive conglomerate which, according to Rogers, is practically barren of coal, containing only "a few thin and profitless seams," while the lower portion, consisting of conglomerates, sandstones, and some shales, holds important coal beds. Rogers calls attention to the character of the Pottsville deposits in this prong, which do not show the coarseness characterizing them farther east, so that in the whole section the chief mass consists of argillaceous sandstones and shales.* Within the main body of the field, eastward from the place of division, the Pottsville retains the same general features to a little beyond Tremont. The thickness here on the southerly side of the field is from 1,100 to 1,200 feet, but on the north side the cross section indicates perhaps 200 feet additional. Near Pottsville the thickness in Sharp mountain is given as 1,200 to 1,350 feet, near Tamaqua as 850 to 1,130 feet, while in the Panther Creek district at the eastern end the variations are extreme. The difference in measurement reported by the several observers is due in great part to disagreement respecting the plane of division between Mauch Chunk and Pottsville. Some incline to take the highest red bed as marking the top of the Lower Carboniferous, while others carry Pottsville to the plane at which coarse, more or less conglomerate beds first appear. The latter seems to be the better plane as marking the beginning of land elevation at the east. The division into coarse Upper and less coarse Lower Pottsville continues throughout, but there is much more conglomerate at the east and the shales of the west are replaced there by sandstone.

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* David White: Succession of the fossil floras of the Pottsville formation in the Southern Anthracite coal field of Pennsylvania. Twentieth Ann. Rep. of U. S. Geol. Survey, 1900, p. 835 et seq.

† The Anthracite fields were studied for the Second Geological Survey of Pennsylvania by Charles A. Ashburner, F. A. Hill, and A. D W. Smith. The reports by these geologists are given in volumes AA and in the annual reports for 1885 and 1886 of that Survey. Mr Smith prepared the summary discussion in the final report published in 1895. The work of these observers is so interwoven that it is difficult to assign to each the credit which belongs to him. The writer desires to make acknowledgment here of indebtedness to them for all information not acknowledged to others in the pages which follow.

Mr David White states that the pebbles in the lower part of the Pottsville within this field are rounded imperfectly, subangular fragments being not rare in the lower third. Quartz pebbles predominate, but those of sandstone and shale are not infrequent. The coarseness increases toward the east, pebbles at the west rarely being larger than a goose's egg, whereas at Hacklebarney tunnel the diameter is sometimes 5 or 6 inches. Higher up in the section the pebbles are better rounded and polished, the rocks become more arenaceous, the shales disappear, so that in the upper 200 to 300 feet the conglomerate is massive, white, persistent, and lithologically comparable to the Homewood of western Pennsylvania.†

Western Middle field.—The Mahanoy basins form the southern strip of this field, and extend eastwardly beyond the Shamokin or northerly basins, which in their turn have a greater extension toward the west. The Mahanoy near its eastern extremity is practically in contact with the Broad Mountain district of the southern field.

Within the Mahanoy basins the Pottsville is from 830 to 850 feet thick, very coarse in the upper 600 feet, while the lower portion is only moderately coarse, containing some sandstone and shale, though in the western portion conglomerates are found throughout the section. The thickness in the Shamokin basins is from 800 to 600 feet. At the western end it is about 750 feet and the rocks are almost wholly coarse conglomerate. The character and thickness of the formation show comparatively little variation throughout, though the field extends westwardly almost as far as the northern prong of the southern, from which it is separated by not more than fifteen miles. The most notable feature is the great decrease in thickness of the lower or less coarse division.

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* H. D. Rogers: Geology of Pennsylvania, vol. ii, 1858, pp. 191–193. The chief study of the anthracite region, as given in Rogers's report, was by James D. Whelpley and Peter W. Sheafer, but no reference is made to them in the body of the report.

† David White: Op. cit., pp. 764, 765.

Eastern Middle field.—The western half of this field overlaps the western Middle as far as the eastern portion of the Mahanoy basins, while the eastern half extends a little way beyond the eastern point of the Southern. The nearest approach to the western field is in the Silver Creek basins, where one is barely 2 miles from the Mahanoy.

The Pottsville is but 300 to 400 feet thick in the Silver Creek basins—a rapid decrease from the 830 feet in the eastern Mahanoy basin, only 2 or 3 miles away at the south. In the Beaver Meadow basins, north from the last, the mass is a conglomerate, almost 300 feet, interrupted only by a thin coal bed and a bed of black shale. In the Green Mountain basin, west from the last, the thickness is the same, but the bottom 100 feet is less coarse. The Hazleton basins, north from Beaver meadow, show 290 to 300 feet of Pottsville; Black creek and Big Black Creek basins show coarse sandstones and conglomerates, about 200 feet at the west, but increasing eastward to about 290 feet. Still farther north, in the Woodville-Cross Creek basins, one finds at the eastern end 260 feet, mostly conglomerate; near Drifton, borings show much variation—200 to 260 feet—in some cases practically conglomerate throughout; in others, some shales and sandstones. Farther west, in the Little Black Creek basins, the thickness is not far from 240 feet, and the rock is mostly conglomerate, while northward, in the Upper Lehigh and Pond Creek basins, the thickness becomes 180 and then 165 feet—sandstone above and conglomerate below. Evidently the whole of the lower division and not a little of the upper division have disappeared.

Northern field.—The western division of this field is about 12 miles north from the nearest point in the eastern Middle and about 32 miles from the southern border of the Southern field.

According to Mr Smith, the Pottsville is 60 feet thick at the western extremity of the field, but increases eastwardly until it becomes 250 feet near Nanticoke. The rock is very coarse, the pebbles ordinarily as large as a hickory nut, but in many localities as large as a hen's egg. Farther eastward, near Wilkesbarre, the thickness is not far from 200 feet, Mr Winslow's section, in Solomon's gap, showing 220 feet of conglomerate broken only by 14 feet of sandstone and 3 feet of shale. In the Pittston region the thickness is from 163 to 235 feet, while in the Scranton region it varies from 250 feet on the southerly side of the field to 230 at Scranton and about 200 on the northwesterly side. Thus far the rocks have been mostly coarse, and the Pottsville ridges are prominent features of the topography; but beyond the Scranton region the coarseness diminishes, so that in the next division the rock is mostly coarse sandstone to fine conglomerate, with occasional pebbly layers, and the thickness varies from 162 to 247 feet. At the northeasterly extremity of the field the thickness decreases from 220 feet, near Carbondale, to 125 feet near Forest City, and the rock becomes a coarse sandstone with "pea conglomerates."

Coal beds of the Anthracite fields.—Having passed in review the general characteristics of the Pottsville rocks, one is prepared to take up consideration of the coal beds.

The Pottsville coal beds of the Anthracite fields are usually spoken of as the "Lykens Valley beds," owing to their importance within the district of that name in the western part of the Southern field.

Detailed information respecting the Dauphin area or southern prong of the Southern field is no longer available. This region was studied nearly 70 years ago by Mr Richard C. Taylor, when mines were in operation, but the coal was found to be so badly broken as to be unprofitable, the mines were abandoned, and later writers have depended almost wholly on Mr Taylor's descriptions.

Recent studies by Mr David White have shown that Mr Taylor was misled by the topographical conditions toward the eastern portion of the area, and that the beds there referred by him to the Pottsville interval are for the most part of Allegheny age. Mr White has shown, however, that the Pottsville is present in that region, but the coal beds have not been exploited, and nothing is known respecting them. It is well to introduce here the typical section obtained at Pottsville by Mr White. Somewhat condensed, it is

	Feet.	Inches
1. *Buck Mountain coal bed*	0	0
2. Coarse conglomerate sandstone	43	6
3. *Coal bed*	0	6
4. Shale with plants	23	0
5. *Coal bed*	0	8
6. Shales and flags	22	0
7. Conglomerate with shale, 8 feet	125	6
8. *Coal* and shale with plants (N)	2	0
9. Sandstone and conglomerate	31	0
10. *Coaly* shale with plants (M)	1	8
11. Conglomerate with shale, 2 feet 6 inches	127	6
12. Dark shale with plants (L)	8	0
13. Sandstone and conglomerate	26	0
14. *Coal bed*	0	6
15. Sandstone	6	3
16. *Coal bed*	1	0
17. Conglomerate sandstone	30	0

	Feet.	Inches
18. Dark shale with plants (K)	3	0
19. Pebbly sandstone	12	0
20. Dark shale with plants, *coal,* 6 inches (J)	8	6
21. Conglomerate with shale 3 feet	25	9
22. *Coal bed*	0	6
23. Conglomerate sandstone	29	8
24. Conglomerate shale with plants (I)	20	0
25. Dark shale with plants (H)	11	8
26. Sandstone and conglomerate, plants (G)	37	0
27. Fireclay and shale with plants (F)	6	0
28. Conglomerate and sandstone	29	6
29. Sandstone with plants (E)	5	0
30. Sandstone, conglomerate, *coaly* shale	64	6
31. *Coal bed*	0	4
32. Fireclay, dark shales, plants (D)	7	6
33. Sandstone and conglomerate	58	0
34. Very dark shales with plants (C)	3	0
35. *Coal bed*	1	0
36. Conglomerate, sandstone, some shale	212	0
37. Dark sandy shales with plants (B)	0	4
38. Sandstone, shale, and conglomerate	195	0
39. Red shale with plants (A)	9	0

in all, somewhat more than 1,200 feet. The thickness is almost 150 feet less than is given by the Pennsylvania Survey reports, but the difference is due mostly to choice of plane for division from Lower Carboniferous. The lettered beds are those from which Mr White made collections of fossil plants. The coal beds in this section are wholly unimportant, but the horizons are at 43, 66, 214, 248, 398, 405, 458, 484, 686, 730, and 802 feet below the Buck Mountain coal bed, the lowest being at somewhat more than 400 feet above the assumed bottom of the formation.*

Returning now to the west portion of the field, one finds in the southern portion just east of the origin of the southern prong a full section obtained at the Kalmia and Lincoln collieries. Condensed, it is as follows, the topmost coal being at 48 feet below the Buck mountain.†

	Feet.	Inches
1. *Coal bed*	2	0
2. Mostly conglomerate	249	0
3. *Lykens Valley coal bed,* No. 1	10	0
4. Conglomerate, some sandstone and shale	287	0
5. *Coal* and shale	2	9
6. Sandstone and conglomerate	29	6

---

* David White, op. cit., pl. clxxxi.

† Atlas Southern Anthracite Field, AA, 4*b*, columnar section, sheet xi.

	Feet.	Inches
7. *Coal* and shale	1	6
8. Sandstone and conglomerate	38	6
9. *Lykens Valley coal bed,* No. 2	3	0
10. Slate	9	0
11. *Lykens Valley coal bed,* No. 3	4	9
12. Sandstone conglomerate and shale	85	6
13. *Coal bed*	0	10
14. Slate	4	6
15. *Coal bed*	1	6
16. Shale, sandstone, and some conglomerate	107	0
17. *Coal bed*	1	6
18. Sandstone conglomerate and shale	44	0
19. *Lykens Valley coal bed,* No. 5	5	2
22. Sandstone, shale, and conglomerate	70	0
23. *Lykens Valley coal bed,* No. 6	2	11
24. Sandstone	5	0
25. *Coal bed*	0	6
26. Shales and sandstones to 1,475 feet		

The coals in this section are at 48, 300, 597, 629, 669, 681, 771, 885, 930, 1,053, and 1,128 feet below the Buck Mountain coal bed. Mr White would draw the line for base of Pottsville at about 20 feet below number 25, thus giving somewhat more than 1,150 feet for the thickness. The numbered beds have been mined. Coals numbers 2 and 3 may be regarded as one bed, for at New Lincoln colliery they are separated by a mere parting. The division between Upper and Lower Pottsville may be made at a few feet below Lykens Valley number 3, for above that the rocks are more massive than below. Here, too, Mr White finds reason for a paleontological separation. He visited some of the old workings at the extreme western end of the southern prong, which were described by Mr Taylor. Though the slates on the dumps were much disintegrated, he was able to recognize the plant remains, and thereby to determine that the whole of the Pottsville is represented there.

The relations in the northern prong are quite similar. A series of borings near the western extremity showed eleven streaks of coal, 1 inch to 3 feet 2 inches, but two of these become 5 and 9 feet thick within a short distance. In the Lykens Valley region, farther east, the beds of the upper division above numbers 2 and 3 are wanting, those beds, united into about 5 feet of shale and coal, being separated by somewhat more than 600 feet of mostly conglomerate from the Buck Mountain horizon above. The Whites coal bed, regarded as number 4, is at 825 feet, and number 5 is at 1,056 feet, while number 6 and the little coal below are at 1,131 and 1,175 respectively. The anomalous interval is that of the Whites bed, which is more than 100 feet higher in the column than in the southern section, while the other beds are almost exactly at the same horizons as in the Kalmia-Lincoln section. The lowest coal is about 200 feet above the bottom of the formation. The coal beds of the upper division have practically disappeared in this prong; number 1 is but a mere streak and numbers 2 and 3 are represented only by coaly shale. The thin beds belonging between 3 and 4 are present at about 100 and 140 feet below 3, so that all the beds of the lower division are present and several of them attain much greater thickness than in the Kalmia-Lincoln section. Farther east, however, number 1 is occasionally of workable thickness.

As one passes eastwardly beyond the union of the prongs, he finds the beds of the upper division increasing in importance, so that at Tremont the workable beds are at 554, 606, and 663 feet below the Buck Mountain horizon.* At Pottsville, Mr David White, after comparison of the fossil plants collected at the various localities, places his plant bed *L* at the horizon of Lykens Valley coal bed number 1; he regards the plant beds *H* and *I* as representing the Lykens 2 and 3, and plant beds *D* and *C* as approximately equivalent to numbers 4 and 5. Bed *C* is approximately 800 feet below the Buck Mountain horizon and 400 feet above the bottom of the Pottsville. The Upper Pottsville is about 550 feet thick, showing a decrease eastwardly; a similar decrease is apparent in the coal-bearing portion of the Lower Pottsville with an increase in the basal portion. It is worthy of notice that alike in the Upper and in the Lower, the conditions within the Pottsville area were unfavorable to accumulation of coal.

Toward the eastern end of the field, two beds are present in Locust gap, north from Tamaqua, at 240 and 385 feet below the Buck Mountain, at approximately the horizons of the fourth and fifth coal streaks near Pottsville. In the Panther Creek district the only coal is in the upper portion. But in the Broad Mountain, or most northerly division of this field, traces of coal have been found in the Altamont boring at approximately 26, 48, 160, 780, 940, 1,010 feet below the Buck Mountain; but the thickness is not more than 4 inches except in the highest, which is 2 feet 2 inches. It is possible that this bed is a split from the Buck Mountain. Another boring in the same district shows coals at 190, 250, 370, 410, 460 to 475 feet, of which all are mere streaks except the lowest, which is from 3 to 4 feet thick and is known as the "Lower Lykens coal." As the thickness of Pottsville here is given as approximately 1,200 feet, it would appear as though this coal should be taken as belonging to the Upper Pottsville and not lower than Lykens number 3.

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*These figures are approximate, having been obtained by measurements on the diagrams of the columnar section sheets, and not by adding the detailed thicknesses. This remark applies to all the intervals given hereafter in these fields.

Passing into the western Middle field, one finds the Pottsville coal beds present and important at the western extremity of the Shamokin or northern basins, where three beds have been at 130, 288, and 419 feet below the Buck Mountain, with thicknesses of 5, 11, and 10 feet respectively. Farther east, at New Franklin, the succession is

	Feet.	Inches
Buck Mountain coal bed		
Interval	200	0
Coal bed III	5 to 10	0
Interval from *Buck Mountain*	320	0
Coal bed II	6 to 8	0
Interval from *Buck Mountain*	470	0
Coal bed I	10	0
Interval from *Buck Mountain*	570	0
Coal bed 0	5	8

The total thickness of Pottsville in this field is between 700 and 800 feet; so that the coal bed 0 is to be regarded as certainly in the Lower Pottsville, and possibly coal bed I should be placed there also. Near Shamokin, number II is 343 feet, and a new bed, IV, appears at 81 feet. The beds III and II are reported at many places in the central portions of the Shamokin, and occasionally they become of workable thickness. Near mount Carmel, in the eastern portion of the basin, a boring shows coals at approximately 38, 58, 219, 293, 674, and 708 feet, and the lowest is known as Lykens number 5, which is a not improbable reference. It is of workable thickness and is very near the bottom of the formation. Elsewhere, however, the coals appear to be almost wholly in the Upper Pottsville, those at Natalie being at 220 and 260; Potts tunnel, 240 and 325; those at Belmore colliery 146 and 232 feet below the Buck Mountain.

In the western portion of the Mahanoy basin, beds were found near Ashland at 240 and 325 feet. Farther east, between Shenandoah and Mahanoy City, traces of coal were found at 233 and 340 feet and a bed 3 feet 8 inches thick at 500 feet, while at the eastern end of the basin 3 feet of coal was found at 420 feet, with no other in the section. Evidently the coals of both divisions are represented in this southern basin.

In the eastern Middle the thickness of the Pottsville varies from 440 feet in the most southerly basin to 165 in the most northerly. Apparently the whole of the Lower Pottsville is wanting, and for the most part even the lower coals of the upper division seem to be absent. The records of borings are numerous, but the occurrence of the coal beds is irregular, as though petty areas alone received deposits, while the varying intervals suggest great irregularity in subsidence.

In the most southerly basins a bed known as the "Alpha," and sometimes of workable thickness, is present at 83 feet below the Buck Mountain. In the next basins north borings near Beaver meadow found coal at 27 to 38, 89, and 148 feet, while one at Beaver meadow found no coal in 235 feet. At Honey brook, 6 or 7 miles west, thin streaks were found at 16 and 56 feet; but at a little distance northwest another boring found only the Alpha, about 100 feet and 6 feet thick. In the Hazleton basin there seem to be no coals at both ends of the basin, though at Hazleton the Alpha is present at 157 feet, and near Stockton two thin streaks are present in the upper 50 feet. No coals appear in any of the Green Mountain sections, but Mr Smith states that the Alpha, too thin to be mined, has been found in several shafts.

At the eastern extremity of the Black Creek basin, where the Pottsville is about 300 feet thick, no coal is present in the upper half; but borings near Jeddo found streaks at 28 and 85 feet, while one at a little way south passed through the whole formation without finding a trace. Near Harleigh, at the western extremity of the basin, one boring shows streaks at 72 and 160. Another finds them at 24, 60, 77, and 120. Northward, near Tomhicken, in the next basin, coal is found in several borings at 53, 65, 72, 76, and 100 feet, but all are regarded as belonging to one bed. Such variations are much less than those in the intervals between the " splits " of the Mammoth bed within this area, which have been proved up by continuous workings. Westward beyond Tomhicken, in this as well as the little McCauley basins, the Pottsville coals are practically unrepresented, having been found only near Gowen, where are two streaks at 45 and 90 feet.

Northward, in the eastern portion of Little Black Creek basin, near Hollywood, the only coal is a thin bed at 84 feet; but 2 miles farther east streaks are reported at 68, 93, and 107 feet; 6 miles farther east one boring finds no coal in 190 feet, while another gives 1 and 3 feet at 24 and 75 feet. In the Upper Lehigh the most northerly basin, where the Pottsville is but 165 feet thick, two coals are reported, the upper at 17 to 35 feet, from 15 to 42 inches thick, and the other, the Alpha, at 98 feet and 52 inches thick. The persistent horizon in this field is that of the Alpha, varying from 60 to 150 feet below the Buck Mountain. Above it are two others, which in many places show thin streaks of coal, but the lower streak may be only a split from the Alpha.

In the Northern field one finds at some localities a bed known as coal bed "A," very near the middle of the Pottsville. Its distribution is uncertain. The bed is present in the southern district of this field, where its thickness is from 1 inch to 3 feet; but it appears to be absent from most of the other districts, though traces of it are shown near

Lackawanna about midway in the field. Its place is approximately that of the Alpha. Dr I. C. White discovered in Lackawanna county a black shale within 3 or 4 feet of the bottom of the Pottsville, which he named "Campbells Ledge black slate." It contains no coal at the typical locality, but near Nanticoke, in Luzerne county, he found it in part a coal shale.* There, according to Mr Smith, it contains 8 inches of impure coal. It has been recognized as far north as the middle of the Jermyn-Priceville division, where it is somewhat coaly. It has yielded immense numbers of fossil plants.

The thinning out of the Pottsville in this northwesterly direction is due to the loss of its lower members. The Lower Pottsville, so thick in the Southern field, is greatly diminished in the western Middle and wholly disappears in the eastern Middle, as evidently does also much of the Upper Pottsville. The stratigraphical evidence is in accord with Mr David White's conclusion, based on the study of the plant remains, that the Campbells Ledge coal bed can not be older than the Lykens Valley coal bed number 1.†

Broad Top field.—The insignificant area of Mississippian in Fulton county of Pennsylvania represents some portion of the Middle Anthracite field, while the Broad Top coal field of Fulton, Bedford, and Huntingdon counties is clearly equivalent to the extension of the Northern field.

Mr Ashburner found a thickness of 280 feet on the east side of Broad Top, which he divided as follows:

	Feet
Piedmont sandstone	160
Mount Savage group	40
Lower member	80

The Piedmont sandstone is very largely conglomerate, coarsest in the middle. The Mount Savage group shows above the middle a coal bed which was taken to be the same with that which in Maryland had been termed the "Mount Savage," but there is room for doubt respecting the identification. The lower member is described as a hard massive sandstone with some conglomerate midway. The coal bed is persistent on this side of the field.‡

Dr I. C. White studied the northerly and northwest side of the field, where he found only 160 feet, in which he recognizes the members of the western Pennsylvania section.

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*I. C. White: Geology of the Susquehanna Region (G 7), 1883, pp. 39–42.

†David White: Op. cit., p. 819.

‡C. A. Ashburner: Aughwick Valley and East Broad Top District (F), 1878, p. 191.

	Feet
Homewood sandstone	80
Mercer shales and coal bed	20 to 30
Connoquenessing sandstone	50
Sharon shales and coal bed	5 to 15
Sharon sandstone	25

The Homewood is slightly pebbly, but the Connoquenessing is markedly so. Usually the pebbles are not larger than a pea, though occasionally one of egg-size occurs.*

Stevenson studied the southern portion of the field where the section is

	Feet.	Inches
Sandstone	121	
Coal bed		2 to 10
Shale	18	
Coal bed		2
Sandstone	125	

in all, 265 feet, corrected to 250 feet. The upper sandstone is not conglomerate, though portions are very coarse. It contains an irregular coaly streak in the upper portion, which may be equivalent to the Mercer, and so at the horizon of bed A of the Northern field. The shales between the sandstones with the thin coal streaks appear to represent the Campbells Ledge horizon of the Northern field, the Sharon of northwestern Pennsylvania. In the bottom sandstone of the section one must recognize the thickened sandstone of the Campbells Ledge region, which is evidently thickening southward or southeastward, being only 25 feet at Doctor White's locality. It is very coarse in the upper 20 feet, which contains much carbonized wood and at times rests on 5 feet of shale, containing some coaly matter; but this shale occurs only in pockets. These measurements indicate that the Pottsville is thicker on the east and south sides than on the northerly sides. The change is abrupt, for the field is barely 7 miles wide and 20 miles long.†

EASTERN EDGE OF ALLEGHENY PLATEAU

Returning now to the north to follow the edge of the Allegheny plateau, one finds some isolated coal areas—the Mehoopany in Wyoming and the Bernice in Sullivan county. The distance from the former to the nearest point in the Northern field is approximately 25 miles. In 1883 Doctor White called attention to the coal area in western Wyoming, which he identified with the Pottsville. The coal bed underlies a massive conglomerate and rests on dark shales containing abundance of plant forms similar to those in the Campbell Ledge shale of the Northern field. Serious objection to this identification was offered at the time because of the small interval to the Pocono; but this objection is without basis, for the westward thinning of Mauch Chunk and Pocono has been proved abundantly.* Somewhat later Mr Hill made a reconnaissance of this Mehoopany region and succeeded in securing sections which proved that the coal is at the bottom of the Pottsville, as Doctor White had asserted. The coal is 2 feet 10 inches to 3 feet 8 inches thick, impure at the bottom, and resting on fireclay. The Sharon sandstone is absent.† Samples of this coal had been procured in 1879 and were analyzed by Mr A. S. McCreath. It has a fuel ratio of 6.1 and 5.1 in the two benches, thus showing a composition very like that of the Lykens Valley coal.‡

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* I. C. White: Geology of Huntingdon County (T 3), 1885, p. 70.

† J. J. Stevenson: Geology of Bedford and Fulton Counties (T 2), 1882, pp. 65, 259.

The Bernice coal field of Sullivan, west from Wyoming, was studied by Mr Platt, who there found two coal beds, *A* and *B*, 60 feet apart. He evidently regarded both coal beds as belonging to the Allegheny, for he gives the Pottsville thickness as but 70 feet, that being the distance from the lower coal *A* to the Lower Carboniferous red shales at the west end of the basin. In one place he refers to a massive conglomerate above coal bed *A*, and in another describes a lower conglomerate, below the coal bed, as coarser than that above. His sections show that 52 feet of massive rock overlie coal bed *A*, while below it are 60 to 70 feet, making the total thickness not far from 120 feet. Mr Ashburner gives the thickness as from 100 to 110 feet.§

This little field was studied carefully by Mr Ashburner and also by Mr C. R. Claghorn, whose work is quoted by Mr Smith. They regard both beds as Pottsville, and Mr Claghorn estimates the thickness of the formation at 180 feet. Mr Smith, however, thinks that only the lower bed is Pottsville, looking on the upper bed as the equivalent of the anthracite Buck Mountain. The character of the rocks supports this conclusion, which is strengthened further by the relations of the plant remains, as determined by Mr David White. This is not the Campbells Ledge bed; it may be at the horizon of the upper bed of the Northern field, at the Mercer horizon.|| Clearly the Sharon sandstone is lacking in this area.

The composition of coal from this lower bed shows strange variations. Samples obtained from the western end of the petty area have a fuel ratio of 8.4 with less than 1.5 per cent of water, whereas two samples from

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* I. C. White: Geology of the Susquehanna Region (G 7), 1883, p. 43.

† F. A. Hill: Ann. Rep. Geol. Survey for 1885, pp. 486 to 490.

‡ A. S. McCreath, quoted by F. Platt: Geology of Lycoming and Sullivan Counties (G 2), 1880, p. 226.

§ Franklin Platt: (G 2), pp. 173, 187, 199.
C. A. Ashburner: Ann. Rep. for 1885, p. 466.

|| A. DW. Smith: Final Report, 1895, p 2009.

a mine only a mile and a half farther east have a fuel ratio of 4.4 and 4.6, so that in the interval the coal has changed from anthracite to semibituminous, while it shows additional features which will be discussed in another connection. It is worthy of note that at the latter locality coal bed *B* is mined at 60 feet above bed *A*. Though the coal from the lower bed has a ratio of about 4.5, that from the upper bed is anthracite with the ratio of 10.3.*

No notes are available respecting the petty area in Lycoming county, but on the Allegheny crest in Clinton county Doctor Chance found 129 feet of Pottsville, with a coal bed 2 to 3 feet thick near the bottom of the upper third, showing that the Bernice conditions extend thus far. In Centre county, south of Clinton, Mr d'Invilliers finds about 255 feet of Pottsville on the Allegheny front south from Snowshoe and describes it as a massive sandstone with some layers of rounded white quartz pebbles, some as large as an egg. He makes no reference to coal.† The general section of Blair county on the face of the Alleghenies as made by Mr Sanders is

	Feet.	Inches
Sandstone	14	0
Coal bed	0	1
Fireclay	9	0
Sandstone	100	0
Concealed	100	0

to the first exposure of red shale. The bottom sandstone becomes coarser in the lower part.‡ Here one is perhaps 25 miles west from the Broad Top field.

Farther south in Bedford county one reaches the northern termination of the great syncline which deepens southwardly, so as to hold in Maryland and West Virginia the important coal field known as Mount Savage, Georges creek, as well as by other names in its more southern portions. On its easterly side, within Bedford county, Stevenson found

	Feet.	Inches
Conglomerate	75	0
Coal bed	4	0
Shale and fireclay	20	0
Coal bed	0	4
Shale	5	0
Sandstone with conglomerate	80	0

in all, 184 feet. The upper plate is coarse, with pebbles as large as peas;

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* A. S. McCreath, quoted by F. Platt (G 2), p. 226.

† E. V. d'Invilliers: Geology of Centre County (T 4), 1884, p. 52.

‡ R. H. Sanders: Geology of Blair County (T) 1881, p. 12.

but the lower plate is less coarse.* Doctor White measured the formation on the westerly side of the basin in Somerset county, where the beds rise toward the Allegheny mountains, and obtained the following section:

	Feet.	Inches
1. Massive sandstone	75	0
2. *Mount Savage coal bed*	4	0
3. Mount Savage fireclay	7	6
4. Conglomerate sandstone	125	0
5. Sandstone and shale	11	0
6. *Coal* and shale	0	8
7. Impure fireclay	10	0
8. Shales	20	0
9. Massive sandstone	35	0

in all, 288 feet 2 inches. The same observer measured the formation on the Potomac river near Westernport, Maryland, and Piedmont, West Virginia; also on the western side of the basin, where the succession is †

	Feet.	Inches
1. Sandstone (Homewood)	20	0
2. *Coal bed*	2	0
3. Dark shale with fossil plants	45	0
4. Hard massive sandstone	40	0
5. Shales and sandstone	42	0
6. *Coal bed*	1	6
7. Fireclay, shale, and sandstone	42	0
8. *Coal bed*	1	6
9. Shale and flaggy sandstone	42	0
10. Pebbly sandstone	45	0
11. *Coaly* shale	0	5
12. Sandstone and shale	195	0
13. *Coal bed*	1	0
14. Sandstone and shale	11	0
Total	473	0

Mr O'Harra gives as an average section of the formation in the Potomac region in Maryland the following ‡ (condensed from the original):

	Feet.	Inches
1. Massive sandstone	20	0
2. *Coal bed, Westernport*	2	0
3. Shales and sandstones	127	0

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* J. J. Stevenson (T 2), p. 100.

† I. C. White: Stratigraphy of the Bituminous coal field in Pennsylvania, Ohio, and West Virginia. Bull. U. S. Geol. Survey, no. 65, 1891, p. 186.

‡ C. C. O'Harra: Maryland Geological Survey, Allegany County, 1900, p. 114.

		Feet.	Inches
4.	*Coal bed*	1	6
5.	Fireclay and shale	22	0
6.	*Coal bed, Bloomington*	1	6
7.	Shale, sandstone, and conglomerate	82	0
8.	*Coal* and *coaly* shale	3	0
9.	Shales and sandstone	37	0
	Total	296	0

A comparison of these sections shows noteworthy changes. On the east side of the basin, near the northern extremity, one finds only the two sandstones with intervening coal and shales, as in Broad Top; the upper sandstone there, as at Gladdens run, on the west side is very thick, but at the latter locality a great mass of sandstone is inserted between the coal beds, and the lower plate has become much reduced in thickness. Doctor White's section on the Potomac, as well as that of Mr O'Harra, shows the upper sandstone much reduced in thickness, the lower being represented by numbers 6 and 8 of the former and by numbers 4 and 6 of the latter; but below the bottom sandstone, number 9 of the Gladdens Run section, there are on the easterly side a coal bed and 37 feet of rock, while on the westerly side the section is increased by 200 feet at the bottom, including two coal streaks separated by 195 feet of rock. Further reference will be made to these conditions when the section has been traced southward from northwestern Pennsylvania.

EASTERN COUNTIES OF ALLEGHENY PLATEAU

Returning now to the north.

Bradford county, on the New York border, is north from Sullivan. The Barclay coal basin in the center of the county was studied many years ago by Professor J. P. Lesley and afterward by Mr Platt. Here are two coal beds, named *A* and *B*, as in the Bernice basin of Sullivan. The latter evidently belongs to the Allegheny; the section below it is

	Feet
Fireclay and sandstone	20
Conglomerate	60
Coal bed A	1
Sandstone to red shale	135

Another small area remains in Tioga county, west from Bradford, in which the Pottsville is 200 feet thick, with streaks of coal from half an inch to 2 feet thick. The rock is mostly sandstone, some of it conglomerate. The succession is*

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* F. Platt: Report of progress in Bradford and Tioga Counties (G), 1878, pp. 120, 127, 167, 178.

	Feet.	Inches
1. Sandstone and shale	33	0
2. *Coal bed*	0	3
3. Sandstone and shale	17	0
4. *Kidney coal bed*	2 to	6
5. Sandstone and shale	10	0
6. *Coal bed*	0	½
7. Sandstone and shale	5	0
8. *Coal bed*	0	½
9. Sandstone and shale	88	0
10. *Coal bed*	0	2
11. Sandstone and shale	0	34

Here are clearly the Homewood, the Mercer, the Connoquenessing, and the Sharon of the western Pennsylvania section. Another area exists in southwestern Tioga, which continues into Potter county, where it is known as the Pine Creek basin, but no details are given respecting it further than that the upper plate of the Pottsville is very coarse. In Potter county is the small Coudersport basin which holds the middle and lower members of the Pottsville with a coal bed at 15 feet above the lower member, which is a massive sandstone between 60 and 70 feet thick and shows a good deal of conglomerate. This lower member, clearly the same with the bottom sandstone of the last section, has been proved to be the Olean conglomerate of Ashburner, the Sharon of I. C. White. The coal bed of this Coudersport basin is unimportant, though it has been mined for local use.*

Lycoming county is south from Tioga and west from Sullivan. Mr Hodge's section, near Astonville, showed a thickness of 116 feet, distributed as follows: †

	Feet.	Inches.	Feet
1. Coarse sandstone	30	0	
2. *Coal bed*	2 to 1	4	
3. Fireclay	5	0	
4. *Coal bed*	2	6	to 2
5. Fireclay and shale	5	0	
6. Pebbly sandstone	25	0	
7. *Coaly* shale	2	0	
8. Conglomerate	45	0	

giving still the triple structure, the sandstones separated by shale and coal.

Clinton county is west from Lycoming and south from Potter. In its western portion is a coal area within the same basin with the Blossburg region at the northeastward and the Cambria at the south. Mr Ashburner's section shows

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*Franklin Platt: Geology of Potter County (G3), 1880, pp. 73-78.

† James T. Hodge in Geology of Pennsylvania, 1858, vol. ii, p. 513.

	Feet.	Inches
1. Johnson's run sandstone	55	0
2. *Alton upper coal bed*	4	0
3. Alton shale and sandstone	36	0
4. *Alton lower coal bed*	3	2
5. Kinzua sandstone	33	0
6. *Upper Marshburg coal bed*	1	0
7. Olean conglomerate	Not measured.	

Very frequently another coal bed, the *Alton middle*, appears in sections of this and adjoining counties.*

The section is one within Tioga, Potter, Lycoming, and Clinton, only with variations in thickness or composition of the several members. It is characteristic also of Cameron and Elk, the counties west from Clinton, as well as of McKean, lying north from those counties along the New York border. Thus in Cameron county Mr Ashburner finds

	Feet.	Inches
1. Sandstone	27	0
2. *Coal* and shale	10	8
3. Fireclay and shale	8	0
4. *Coal* and shale	6	0
5. Shale	19	0
6. Sandstone	125	0
Total	195	0

The Connoquenessing (Kinzua) and Sharon (Olean) sandstones are not distinguished in the section, but Mr Ashburner states that a coal bed at times occurs almost midway in the lower sandstone. The section is similar in Elk county, where the Alton coals are frequently thick enough to be mined; so also farther west, in the same county, within Rogers fifth basin, where the total thickness is 182 feet. Sometimes a lower bed, the Lower Marshburg coal bed, is found. The coal beds are extremely irregular in their occurrence, and their variable thickness leads Mr Ashburner to speak of them as lenticular. It may be well to give Mr Ashburner's generalized section for McKean county:

	Feet
1. Johnson Run sandstone	30 to 75
2. *Alton coal group*	20 to 35
3. Kinzua sandstone	45 to 60
4. *Marshburg upper coal* and shale	5 to 15
5. Olean conglomerate	45

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*C. A. Ashburner (G 4), p. 74.

The Johnson Run sandstone is massive and fine grained; it is the Homewood sandstone of Doctor White's type section. The Kinzua is less massive, but more or less pebbly. It is the representative of White's Connoquenessing sandstones and occasionally shows a trace of the Quakertown coal and shale. The Olean is the Sharon sandstone; it is often very coarsely conglomerate, but the coarser portions are lenticular. This is the rock forming the rock city at Olean, in Cattaraugus county of New York. The Alton group is the Mercer group of White, and the Alton coals are strictly equivalent to his Mercer and Tionesta coal beds, They are often three in number within McKean county, at times of workable thickness, but usually of little value, as much because of impurities as of abrupt variations in thickness.*

The dearth of information respecting Clearfield county, south from Cameron and Elk, is remarkable. The formation is above the streams at many localities, but apparently exposures admitting of measurement are exceedingly rare. Mr Franklin Platt estimates the thickness of Pottsville at not less than 200 feet in Boggs township of Clearfield, where the rock is a white quartzose sandstone with much massive fine conglomerate. Doctor Chance states that in Bell township of the same county the pebbles are at times large as a hen's egg. Coal is reported at several localities as occurring in the upper third, evidently some member of the Mercer group.†

In Jefferson county Mr Platt ‡ was able to recognize the Homewood sandstone, the Mercer shales, and the Upper Connoquenessing sandstone. The Homewood is usually coarse and massive with, in many places, white quartz pebbles varying in size from pea to hen's egg. It makes "rock cities" and has an extreme thickness of 60 feet. The Mercer shales are 30 to 80 feet thick, with one to three coal beds, the upper never more than 8 feet below the Homewood. No limestones are here. The Connoquenessing sandstone is 125 feet thick at one locality; but evidently Mr Platt entertained some doubt respecting the exact relations of this great sandstone, as he discovered at one locality a red shale at about 100 feet below the top of the Homewood which bears much resemblance to Shenango.

Doctor White § gives the record of a boring at Brookville which goes far to strengthen Mr Platt's evident doubt, for the thickness assigned to the Pottsville is 372 feet, an extraordinary thickness in comparison with that in Elk and Cameron at the north and in counties at the south.

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*C. A. Ashburner: Geology of McKean County (R), 1880, pp. 49–59; Geology of Elk County (RR), 1885, pp. 69, 127.

A. W. Sheafer: Geology of Cameron County (RR), p. 48.

†H. M. Chance: Rev. of Bit. Coal Measures of Clearfield County (H 7), 1884, pp. 109, 115.

‡W. G. Platt: Jefferson County (H 7), 1881, pp. xxxiii, 84, 90, 125, 158, 165, 173–174, 186, 194–195, 196.

§I. C. White: U. S. Geological Survey Bulletin 65, p. 183.

Cambria and Indiana counties are south from Clearfield and Jefferson. The former reaches to the crest of the Allegheny, where the Pottsville is exposed frequently. The thickness under the Viaduct axis is estimated by Mr Platt at not more than 250 feet, but he gives no measurements in detail.* In eastern Indiana, under the Chestnut Hill arch, he finds within Yellow Creek gap 70 feet of coarse sandstone, with 1 foot of coal very near the bottom; 4 or 5 miles farther south, in Black Lick gap, near Heshbon, the succession is

	Feet
Sandstone	20
Shale	25
Coarse massive sandstone	25

with the bottom not reached, the whole thickness being estimated as somewhat more than 75 feet. At the mouth of this gap exposures are very poor, and the thickness is given as not less than 60 nor more than 100 feet. †

Along the Conemaugh river, which separates Indiana from Westmoreland county, the Pottsville shows noteworthy variations. Near Nineveh, on the west side of Laurel hill, in Westmoreland county, the thickness of sandstone is approximately 150 feet, only moderately coarse, with layers of pea conglomerate. Some sandstone and iron ore underlie it, adding in all about 25 feet to the thickness. No coals were seen, but the exposure is not complete. On the easterly side of the gap made by the river through Chestnut hill, the thickness is not more than 70 feet, mostly fine sandstone and with a 1-foot coal bed at 7 feet from the bottom, almost exactly the same as Mr Platt's section at Yellow Creek gap; but on the west side of the mountain the sandstone has almost wholly disappeared and the mass shows little aside from shales. It is unfortunate that details respecting Clearfield county are wanting, for somewhere within that county the Sharon-Olean conglomerate disappears, though, as will be seen, the Sharon coals and shales persist, being apparently continuous with the Mauch Chunk shales below, so that they were placed in the Lower Carboniferous by Stevenson in his study of this region.‡

Somerset county, south from Cambria and extending eastward to the Allegheny crest, appears to offer few opportunities for measurement of the Pottsville, though that formation is exposed to a greater or less extent at many localities. The only estimate offered by Mr Platt is that of about 200 feet on Haskins run, where coal is present in the upper portion.*

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* William G. Platt: Cambria and Somerset Dist. I (H 2), 1877, p. 45.

† W. G. Platt: Indiana County (H 4), 1878, pp. 125, 101, 187.

‡ J. J. Stevenson (K 3), 1878, pp. 156, 172.

Westmoreland and Fayette counties are west from Somerset, the latter extending to the West Virginia-Maryland line. The great axes of Laurel hill and Chestnut hill increase southward, so that in the eastern portion of these counties the Pottsville is reached in numerous gaps, and one can trace the changes from the Conemaugh to the state line.

In Laurel hill, which separates these counties from Somerset, the sandstone mass, about 150 feet thick, seen on the Conemaugh, may represent the Homewood and Connoquenessing sandstones of White, the Johnsons run and Kinzua sandstones of Ashburner. The Sharon shales and coals underlying this are not shown on the Conemaugh, but within a few miles southward an exposure of 24 feet shows 2 to 4 inches of coal at 10 feet below the sandstone, associated with the iron ores, which, in these counties, are characteristic of this lower division. Farther south the sandstone mass is but 100 feet thick and not very coarse. In the Youghiogheny gap the sandstone is about 100 feet, but distinctly separated into the Homewood (Piedmont of Maryland) and the Connoquenessing sandstones, with a Mercer coal bed, the Mount Savage of Maryland, between them. The Homewood sandstone is about 30 feet thick and much of it is pebbly, in this respect differing little from the Connoquenessing. The coal bed rarely exceeds 15 inches and often is found distributed in fragments through the lower part of the overlying sandstone. The lower or Sharon division is shown in railway cuts below Ohiopyle on the Youghiogheny, where it consists of shales, sandstones, and thin coals. The thickness varies greatly, chiefly in the shales, but the extreme is approximately 140 feet. The sandstone beds are at 40 and 45 feet respectively, and show comparatively little variation. Three thin coal beds were seen here, the lowest at 140 feet below the Connoquenessing. A fourth evidently underlay the sandstone, as its fragments are distributed through the lower portion of that rock. There is nothing here that can be identified directly with the Sharon sandstone, but the great thickness below the Connoquenessing suggests that some portion may be contemporaneous with that deposit.†

Under Chestnut Hill the Pottsville quickly regains its character south from the Conemaugh, for in the Loyalhanna gap it shows 50 feet of sandstone resting on red shales, but without coal. The same thickness of sandstone was seen in the southern part of Westmoreland county, where the lower or Sharon division is about 90 feet thick. The Mount Savage coal bed is here, and at least two thin beds are in the Sharon shales, one of which, directly underlying the Connoquenessing, is shown on the east side of Chestnut Hill.

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*W. G. Platt: Cambria and Somerset Dist. II (H 3), 1878, pp. 141, 146.

‡ J. J. Stevenson (K 3), pp. 82, 101, 134, 177.

In the northern part of Fayette county, beyond the Youghiogheny river, the sandstone mass appears rarely to exceed 60 feet, and almost invariably it rests on a thin coal bed. The sandstone shows a thin coal bed below the middle which probably represents the Mount Savage. The Sharon shales are thin, for the lowest ore bed is but 25 feet below the sandstone—a decided contrast with the thickness at a few miles north and south. Beyond the Youghiogheny, in Dunbar, the sandstone mass is certainly more than 70 feet thick and rests on a coal bed, below which are clays, thin sandstones, and ores for 100 feet, with thin coal beds at 49, 62, and 83 feet. At a few miles farther south, on the west side of the mountain, the Sharon portion is but 70 feet, with much red shale and five thin streaks of coal, while near by it is 80 feet with three coal streaks 8 to 9 inches thick; but at ten miles farther south the thickness is only 45 feet, with apparently but two coals aside from the persistent bed underlying the sandstone mass.*

On the east side of Chestnut hill, along the national road in Fayette county, the Homewood (Piedmont) sandstone is apparently not more than 25 feet thick, and shows some layers of pebbles, rarely larger than a pea, while the lower sandstone appears to be not more than 50 or 60 feet and comparatively fine in grain. The Sharon division here and southward is not less than 120 feet thick and is more shaly than at the exposures along the Youghiogheny. The Mount Savage coal bed is present, with a thickness of at most 4 feet, but only one of the lower coals was seen in the ore pits. The opportunities for study of the lower division were very good twenty-five years ago, for at that time the iron ores were of much local importance, and were mined extensively to supply furnaces along the western slope of Chestnut hill, in Fayette and Westmoreland counties; but those ores are no longer esteemed, and all work was abandoned many years ago, so that during a restudy of the region it was found impossible to obtain any details or even to verify the measurements already reported. Southward the lower division becomes thinner and the sandstone mass thicker. At the most southerly measurement within Fayette county the shales below the Connoquenessing are little more than 50 feet.†

Thus far in the description of Laurel and Chestnut hills the whole section below the massive sandstones has been regarded as belonging to the Sharon portion of the section, for the reason that they were separated from the Pottsville by Stevenson in his reports on the region. But the studies of I. C. White farther south under the same axes make clear that much of the great sandstone of the Youghiogheny section is rather to be regarded as Upper Connoquenessing, so that the persistent coal bed under the Connoquenessing of this description is most probably the equivalent of the Quakertown. The Cheat river, flowing northwestwardly, cuts the Viaduct, Laurel Hill, and Chestnut Hill anticlines in Preston county of West Virginia. Doctor I. C. White studied the section in the several gaps and his results may be given in reverse order (toward the southeast), that the western condition may be compared directly with that already given for the east side of the Allegheny mountains. The Cheat River gap through Chestnut hill is perhaps 15 miles from the National road. The succession on the westerly side of the mountain on Quarry run is

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* J. J. Stevenson (KK), 1877, pp. 142, 174, 187, 195, 196, 210, 261.

† J. J. Stevenson (K 3), pp. 68, 71.

	Feet.	Inches
1. Sandstone	25	0
2. Concealed	40	0
3. Massive pebbly sandstone	75	0
4. *Coal bed*	1	4
5. Black slaty shale	10	0
6. Gray massive sandstone	20	0
7. Shales and *coal* streaks	1	0
8. Sandstone	15	0
9. Shales with iron ore	20	0
Total	197	0

Doctor White places number 9 in the Mauch Chunk; but in view of the presence of the iron ore, evidently representing the "Big Bottom" bed of Fayette and Westmoreland counties, it is included here with the Pottsville for the sake of uniformity with sections previously given. The Mount Savage coal bed should be in the concealed interval. Doctor White regards numbers 6 and 8 as representing the Lower Connoquenessing sandstone, so that the only representative of the Sharon would be in number 9. The little coal bed, number 4, is that which has been observed at so many localities toward the north, where it immediately underlies the second sandstone of those sections, and there is little reason to question the identification with the Quakertown. On the east side of this fold the section is

	Feet.	Inches
1. Sandstone, more or less pebbly	160	0
2. Dark shale, plants	10	0
3. *Coal bed, Quakertown*	1	6
4. Black fissile shale	15	0
5. Concealed	90	0

As at nearly all localities, the Quakertown coal is double The Mount Savage bed is wanting on this side of the axis.

The Pottsville is 245 feet thick on the west side of Laurel hill, including as before the ferriferous shales at the bottom. The mass above the shale is almost wholly sandstone, without any trace of coal; but on the side of Briery mountain (the Viaduct axis of Somerset and Cambria) the Homewood sandstone is distinct with the Mount Savage coal below it.*

Almost fifty years ago Professor W. B. Rogers reported on the iron ores of Chestnut ridge near Doctor White's Quarry Run section. He found at the bottom of the section, below the massive sandstone, 65 feet with five beds of iron ore which are described as evidently the same with those of Fayette and Westmoreland counties. Doctor White's incidental references show that the ores are persistent on Laurel hill.†

Doctor White succeeded in making a detailed section along the Baltimore and Ohio railroad under the Briery (Viaduct) axis within Preston county of West Virginia; it is so important that it is given here almost without condensation.

	Feet.	Inches
1. Sandstone	60	0
2. *Coal bed*	0	5
3. Shale	6	0
4. *Coal bed*	0	5
5. Shales, brown, sandy	45	0
6. *Coal* and coaly shale	2	0
7. Shale	3	0
8. Sandstone	68	0
9. Brown shale, traces of coal	4	0
10. Sandstone	20	0
11. Shale	3	6
12. *Coal bed*	0	5
13. Shale	4	0
14. *Coal bed*	0	4
15. Shales, some iron ore	13	6
16. *Coal bed*	1	0
17. Shales	10	0
18. *Coal bed*	0	4
19. Shales, brown, sandy	25	0
20. *Coal bed*	0	6
21. Brown shale	20	0
22. Sandstone	15	0
23. Buff sandy shale	20	0
24. Massive coarse conglomerate	20	0
Total	342	5

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* I. C. White: Notes on the Geology of West Virginia. Proc. Amer. Phil. Soc., vol. xx, pp. 481, 486, 490, 492, 494.

† W. B. Rogers: Property of the Pridevale Iron Co. Mining Magazine, vol. iii, 1854, pp. 358–362.

This shows a notable increase southward, for under this axis in Somerset county, Mr Platt estimated only about 200 feet. The section can not be compared in detail with those already given, but the typical section can be recognized thus:

	Feet
Homewood sandstone	60
Mercer group, shales, and *coal bed*	57
Connoquenessing	92
Sharon shales and *coal beds*	78
Sharon sandstone with sandy shale	55

In any event, whether or not this grouping be exact in detail, the section shows clearly the presence of the Sharon sandstone at the bottom.

Mr Martin measured the section on the Youghiogheny river in Garrett county, Maryland, almost midway between the last section and that at Westernport. He gives

	Feet.	Inches
1. Massive sandstone, Homewood	50	0
2. Shale	6	0
3. Mount Savage fireclay	4	0
4. *Coal, Mount Savage*	3	0
5. Shale	5	0
6. Sandstone	5	0
7. *Coal, Lower Mercer*	0	10
8. Conglomeritic sandstone, Upper Connoquenessing	75	0
9. Black shale	2	0
10. *Coal, Quakertown*	1	6
11. Shale	0	6
12. Concealed	8	0
13. Massive conglomeritic sandstone, Lower Connoquenessing	75	0
14. Concealed	60	0
15. Shale	5	0
16. *Coal, Sharon*	1	4
17. Shale	0	6
18. Sandstone	25	0
Total	327	8

One recognizes here very clearly the typical section of northwestern Pennsylvania, both members of the Connoquenessing being present as massive more or less conglomerate beds, whereas farther west the lower sandstone, as at so many localities in the northwest, is represented chiefly by sandy shales.* Comparison with the section at Westernport, in Maryland, shows that the Sharon is less important there.

WESTERN COUNTIES OF PENNSYLVANIA

Returning now to the northern line, Warren county is west from McKean, along the New York border. Only isolated patches of the Pottsville remain north and west from the Allegheny river, but some extensive areas are found in the southeastern part of the county. Mr Carll has shown that the lower member of the Pottsville, the Sharon-Olean conglomerate, disappears abruptly in the northeast corner of the county. At the "Pass," about 8 miles west from the McKean line and 7 miles south from the New York line, the section is

	Feet
Sandstone	60
Conglomerate	25
Shenango shales	30
Logan (Shenango) sandstone	

whereas at barely one mile northward the conglomerate has disappeared, and the sandstone rests directly on the Shenango shale. Eastward from the Pass the conglomerate is soon lost, and it is absent for about 2 miles, reappearing at the Quaker Hill mines, where it is very thin. It increases toward the south of east, becoming 8 feet within a mile, where it is but 5 feet above the Logan, and reaching 20 feet at a mile farther east. The overlying sandstone is regarded by Mr Carll as equivalent to the Kinzua (Connoquenessing) sandstone of McKean. The Sharon is persistent westwardly, for it is present in an outlier within Sugar Grove township, 16 miles west from the Pass and about 5 miles south from the New York boundary.

At the Pass the Connoquenessing and Sharon are in contact, but at the Quaker Hill mines, about 2 miles east, they are separated by

	Feet.	Inches
Shales	40	0
Coal	0	3
Shale	4	9
Coal	1	6 to 2 feet.
Shale	1	0

in all, about 47 feet. The shale between the coal layers is often replaced in part by conglomerate, in which the pebbles, like those of the Sharon conglomerate below, are coated with carbonaceous matter. This curious little basin, containing not more than 50 acres, shows a dip from all directions toward the center. The dip is high, reaching even 45 degrees, and the coal is badly crushed; but the fuel ratio is 1.6. This is the Upper Marshburg coal bed of McKean and adjacent counties, the Sharon of counties along the Ohio line.

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* George C. Martin: Maryland Geological Survey. The Geology of Garrett County, 1902, p. 103.

The whole section is present in Allegheny township south from the river, where Mr Randall measured

	Feet
1. Massive sandstone	30
2. Shales and thin *coal bed*	70
3. Concealed	20
4. Massive sandstone	65
5. Conglomerate	10
6. Shales and thin *coal bed*	45 to 50
7. Sandstone	45 to 70

with an average of about 300 feet for the whole column. It is easy to recognize the Johnson Run, Kinzua, and Olean sandstones with the Alton and Marshburg shales of counties already described. The rapid increase of the Sharon (Olean) sandstone is noteworthy, for the Quaker Hill mines are but 4 or 5 miles away.

Doctor Chance's section, obtained at a little distance farther east, where the exposures are incomplete, gives the sandstones as 30, 20, and 77 feet, the interval from Johnson run (Homewood) to Kinzua being 129 feet, with much of the lower portion concealed. Two Alton coal beds are present.*

Forest county south from Warren shows Pottsville on all of the uplands. Mr Ashburner's carefully measured sections make the relations very clear. In Jenks township he finds

	Feet
Johnson Run sandstone	70
Shales and *coal beds*	10 to 25
Kinzua sandstone	90
Shales	10
Sandstone	100

with an average of nearly 300 feet. The Kinzua sandstone is double, divided almost midway by 10 feet of shale apparently containing a coal bed at some localities; so that here are the two Connoquenessing sandstones and the included Quakertown shales of the Ohio line counties. The Sharon sandstone has increased greatly and some of the layers are conglomerate, but the pebbles are distributed irregularly. Four coal beds of the Alton (Mercer) group were seen, and the Marshburg (Sharon) bed is shown occasionally in the dark shales overlying the Olean. All of the coal beds are irregular, but are fairly persistent, having been observed at many places.*

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* J. F. Carll: Geology of Warren County (I 4), 1883, pp. 302, 304, 325–330, and 364.

Crawford county is west from Warren and extends to the Ohio line. The Pottsville remains only in the southern part, where Doctor White obtained the section, so often referred to in the foregoing pages. It is

	Feet
Homewood sandstone	50
Mercer group	30
Connoquenessing group	120
Sharon shales	50
Sharon conglomerate	45

with an extreme thickness of 300 feet. As in Forest, the Connoquenessing is double; the sandstones are each 35 feet, a little thinner than in Forest, but the intervening shale in crossing Venango county has thickened to 50 feet. The upper sandstone, white to grayish white, is more or less pebbly. The intervening shales, the Quakertown of White, show coal at only one locality. The lower sandstone is hard, coarse, and brown, often micaceous and sometimes pebbly. It is less persistent than the upper, being divided at times by 20 to 30 feet of shale.

The Sharon shales are from 25 to 50 feet thick, the variation being due to that in the Lower Connoquenessing sandstone. Where thick, they show a coal bed in the upper part; the Sharon bed, below the middle, is thin and poor, appearing only occasionally along the outcrop and rarely becoming thick enough to be worked.

The Sharon sandstone retains the character so frequently observed in the counties already crossed, in that the upper part is sandstone, while the lower part is a coarse conglomerate for about 10 feet. The pebbles are not so large in Crawford as at more eastern localities, being seldom larger than a hen's egg, whereas at Tidioute, in Warren, they are sometimes as large as a goose's egg. Everywhere the pebbles are ovoid, though Ashburner speaks of them in Forest county as occasionally rather angular. The thickness has diminished from 100 to less than 50 feet in crossing Venango county. The northern line of outcrop is from the Ohio line in southwest Crawford to northeast Warren.†

In Mercer county south from Crawford the Homewood sandstone is from 30 to 70 feet, being thickest at the north and varying from good building stone to coarse conglomerate. New members appear in the Mercer group, which here contains two coal beds and two limestones. The upper limestone is less persistent than the lower, which is present in by far the greater part of the county. These do not extend into Crawford, but disappear northwardly at about 3 miles south from the line of that county. Iron ore is associated with both limestones, sometimes even replaces them. Both beds contain familiar Coal Measure fossils. A coal bed underlies each limestone, and at one locality near the Venango line there is an intermediate bed at 6 feet above the Lower Mercer limestone. These are the Alton beds of Ashburner.

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* C. A. Ashburner,: Report of Progress in Forest County (RR), 1885, pp. 307–316.

† I. C. White: Geology of Crawford and Erie Counties (Q 4), 1881, pp. 55, 56.

The Upper Connoquenessing sandstone is from 40 to 60 feet thick, light gray, and pebbly near the top. The Lower Connoquenessing is from 30 to 89 feet, varying abruptly and for the most part at the expense of the Sharon shales. The Quakertown shales show the coal bed in the upper portion and vary from 20 to 50 feet. The Sharon shales are usually less than 30 feet, but where the overlying sandstone is thin they become 70 feet and show thin coals at 65, 50 to 45, and 22 feet above the Sharon coal bed. The last attains its chief importance in this county, but its occurrence is very uncertain, as the coal is in pots or saucer-shaped deposits which are largest and carry the best coal on the Ohio side of the county, where the thickness is sometimes 5 feet.

The Sharon sandstone is diminishing southwardly, for it is only 20 feet thick at Sharon, and it disappears somewhere in the southern part of the county. Along the Ohio border it shows the usual features, but eastward it is for the most part only a massive sandstone, at times becoming flaggy.*

In Lawrence county, south from Mercer, the Homewood sandstone, about 40 feet thick, varies from sandstone to shale. It is a sandstone near the Mercer line, as also in the southern tier of townships bordering upon Beaver county, but in a great part of the county it is apparently shale. At never more than 5 feet below this sandstone is the Tionesta coal bed of I. C. White, which appears to be at the horizon of the Mount Savage coal bed. It extends northward almost to the Mercer line and appears to be persistent, since wherever its place is exposed one finds either a bed of impure coal or a deposit of very black bituminous shales.

The Mercer group shows in by far the greater part of the county the two limestones and coal beds. The Upper Mercer limestone, as in Mercer county, is much more variable than the Lower, and not infrequently is represented only by its ore bed. Both limestones are present in all of the townships along the Ohio line, and notable variation appears only as one approaches the Butler county line at the east; yet both are present in the extreme southeast corner of the county.

The Connoquenessing sandstones are as variable as the Homewood.

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* I. C. White: Geology of Mercer County (Q 3), 1880, pp. 33–58.

Massive in the northern part of the county, they become shaly in other portions. At times they form a continuous mass of sandstone, and in southeastern Lawrence the Upper Connoquenessing is continuous with the Homewood sandstone, 130 feet thick. The Quakertown shales are sandy. Their coal is of workable thickness at Quakertown, on the Ohio line. Elsewhere it is thin, and in the southeastern part of the county it is represented only by carbonaceous shale.

The Sharon shales, with their iron, persist, and where exposed rest upon the Shenango shales; but in the southern part of the county two well records show a sandstone below them which may represent the Sharon. The Sharon coal bed disappears southward in the northern part of the county, but at many localities elsewhere its horizon is marked by black shales, occasionally containing coaly streaks.*

In Beaver county, south from Lawrence along the Ohio line, the Pottsville passes below cover at about 6 miles from the Lawrence border.

The notable feature is the extraordinary thickening of the Homewood sandstone at about 4 miles south from Lawrence county. At the northern line of Beaver the mass is of moderate thickness and is overlain by shales of the Allegheny formation, which include some thin coal beds; but near Homewood and thence southward for more than a mile it is from 150 to 160 feet thick, the increase being at the expense of the overlying beds, which it has replaced up to the Ferriferous limestone. Farther south the thickness diminishes, becoming only 60 feet within 2 miles, and the rock passes under cover along the Beaver river near New Brighton.

The Tionesta coal bed is present directly under the Homewood sandstone. The Upper Mercer coal bed and limestone are apparently absent throughout, but the Lower Mercer coal bed and limestone are present in the northern part of the county, though they evidently disappear within a short distance southward. The Connoquenessing sandstones appear to persist, being reported in the oil-well records as far as the southern border of the county, and the Quakertown shales are sandy. The Sharon coal bed, as well as the Sharon sandstone, is absent, but the plant-bearing shales marking the place of the coal persist.†

There remains a group of counties east from those along the Ohio line. Venango county, south from Warren and east from Crawford and Lawrence, evidently shows conditions similar to those of Crawford. The geological investigations in this county were made with especial reference to the petroleum interests, and few details respecting the Pottsville are given in the report, as it contains little of economic value; but

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* I. C. White: Geology of Lawrence County (Q 2), 1879, pp. 52-70.

† I. C. White: Report of Progress in Beaver River District (Q), 1878, pp. 65-72.

Mr Carll shows that the three sandstones are distinct, with the intervening Mercer and Sharon shales. No reference is made to the Mercer limestones, but the several coals of the section are present, and evidently as uncertain in occurrence as in the western counties. The sandstones are named Homewood, Connoquenessing, and Garland, the last being the Sharon of White, the Olean of Ashburner.*

Clarion county, south from Venango, has Jefferson at the east. Doctor Chance's generalized section enables us to recognize here the series as on the Ohio line. It is

	Feet
Homewood	30 to 50
Mercer	35
Upper Connoquenessing	40
Quakertown	25
Lower Connoquenessing and Sharon	130

The Homewood is often shaly, and the change from a coarse, more or less pebbly, sandstone is often abrupt. It is equally variable in thickness, the extremes being 15 and 60 feet. The Mercer group is not shown in detail in the northern part of the county, but the Lower Mercer coal bed is present near Edinburg, and it may be the bed seen at one locality on the eastern side of the county. Both Mercer coals are shown on the Allegheny river in the southern part. The Mercer limestones are absent, but in the extreme southeast an ore bed was seen near the place of the lower bed. The Upper Connoquenessing sandstone is distinct throughout, separated by 4 to 35 feet of Quakertown shales from the lower sandstone, which in the central part of the county is continuous with the Sharon sandstone; but the Sharon shales, 45 feet thick, are present in the southeast corner of the county, where the sandstones are 50 and 40 feet respectively. The Quakertown and Sharon coal beds are unrepresented.†

Butler county is south from Venango and east from Mercer and Lawrence.

The Homewood sandstone is shown occasionally in the northern part of the county as a coarse, iron-stained sandstone at least 30 feet thick. It is thinner along the Mercer and Lawrence line, varying from 15 to 30 feet, but is thicker in the central portion, while on the eastern side, adjoining Armstrong county, it is from 15 to 80 feet, varying at the expense of the Mercer shales.

The "Tionesta coal bed" is present on the west side, adjoining Lawrence, where it underlies the Homewood and is 2 feet thick, but it was not observed elsewhere. The Mercer coals are shown in the eastern part wherever their place has not been taken by the sandstone. The extreme thickness of Mercer is 122 feet, and the limestones are wanting. The Connoquenessing sandstones are exposed on the Armstrong border, where they are each 20 feet, separated by 43 feet of Quakertown shales, showing no coal.*

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*J. F. Carll: Geology of the Oil Regions (I 3), 1880, p. 14.

† H. M. Chance: Geology of Clarion County (V 2), 1880, pp. 73, 106, 116, 123, 134, 147, 162, 164, 177.

Armstrong county is south from Clarion, between Butler at the west and Indiana at the east. On the northern border, along Red Bank creek, the section is

	Feet
Homewood †	50 to 75
Mercer	40
Connoquenessing	150
Sharon shale	13
Sharon sandstone	50

The Mercer coal beds are represented by a 2-inch streak in the upper portion, but there is no trace of the Mercer limestones. The Connoquenessing is a continuous mass of sandstone along the boundary between Clarion and Armstrong for several miles, and, like the Sharon sandstone below, appears to be without pebbles. Farther northwest, on the Butler county border, the condition is the same, for 115 feet of Connoquenessing was seen above the river; but both of the Mercer coal beds are present there, as they are also at another locality 8 or 9 miles southwest.

In the northern half of the county, east from the Allegheny river, the Homewood sandstone is shown at several localities along that river, disappearing finally under the stream at about 5 miles above Kittanning. An interesting section is shown on Mahoning creek within 3 or 4 miles of the Indiana line. It is given here in detail:

	Feet.	Feet
Homewood sandstone	..	40
Concealed	..	12
Mercer group	..	96
Black shale	10	..
Sandstone	10	..
Shale	17	..
Limestone	6	..
Concealed	50	..
Shales and ore	13	..
Upper Connoquenessing	..	42
Quakertown shales, sandy, seen	..	10

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* H. M. Chance: Northern Townships of Butler County (V), 1879, pp. 42, 70, 96, 102, 118, 122, 132.

† Here, as in several other sections, the writer has applied the now accepted names to parts of the section, though they were not used by the authors of reports from which the records are taken. For discussion of the relation, here accepted, see under "Correlation" in a later portion of this paper.

Here, apparently at the place of the Upper Mercer limestone, is a limestone bearing no resemblance to that bed either in structure or appearance, but, according to Mr Platt, almost exactly similar to the Tuscumbia limestone or Silicious limestone as shown in the Chestnut Hill gaps. Its appearance here, so far away from the nearest occurrence of any Mercer limestone, shows it to be a purely local feature, for whose occurrence no explanation is available. It disappears very quickly in all directions. The Black shale of the section is near the place of the Tionesta coal bed.

The Homewood sandstone is thicker toward the Indiana border, on Mahoning creek, where it is 70 feet, and both Mercer coal beds are present at about 2 miles above the last locality of the last section. The whole series is exposed on the Allegheny, at the mouth of Mahoning creek, about 12 miles from the Indiana border and 4 miles south from Clarion. The section is practically the same as on Red Bank creek, but the Mercer coal beds are not shown and only thin streaks of coaly matter occur in the Sharon shales, which there are 38 feet thick.

The most southerly exposure of any part of the Pottsville west from Chestnut hill is on Cowanshannock creek, say 40 miles northwest from the Conemaugh gap. There 63 feet are shown belonging to the Homewood sandstone in several massive layers, without pebbles and separated by shale.*

The Pottsville passes under cover in Armstrong, Butler, and Beaver counties at a few miles south from their northern boundaries. Thence southward in those counties, in Allegheny, Washington, and Greene, as well as in Westmoreland and Fayette, west from Chestnut hill, information can be obtained only from records of oil borings, which are not wholly consistent; but those records are so numerous that it is possible to trace the formations with close approximation.

The record at Petrolia, in Butler county, is

	Feet
Homewood sandstone	66
Shales and sandstones	145
Sandstone	148

Here one is almost due west from the Red Bank Creek region of Clarion and Armstrong. The succession is clearer on the western side of the county, where one finds

	Feet
Homewood	18
Mercer group	110
Upper Connoquenessing	65
Shale	3
Sandstone and shale	100

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*W. G. Platt: Report of Progress in Armstrong County (H 5), 1880, pp. 88, 139, 143, 185, 194, 207, 215, 231.

In southern Butler a well on Thorn creek, about midway east and west in the county, shows 220 feet of sandstone at the bottom,* while a record in the extreme southeast part, near the Allegheny river, shows

	Feet
Homewood	65
Mercer	103
Upper Connoquenessing	75
Quakertown shale	40
Sandstone	200

A coal bed, the Tionesta, is here at 8 feet below the Homewood, and much black sand is present in the lower portion of the Mercer. The great mass of sandstone below the Quakertown represents the Lower Connoquenessing and the Sharon shales and sandstone, with, as in Butler, perhaps some beds of greater age.

At New Brighton, in Beaver county, the section is

	Feet
Homewood	53
Tionesta coal bed	1
Mercer group	112
Upper Connoquenessing	41
Quakertown shales	40
Lower Connoquenessing	50

The Mercer and Quakertown coals are not reported. A record in southeastern Beaver shows an extraordinary thickening of the Homewood sandstone similar to that already mentioned as observed near Homewood in this county. The thickness is 120 feet, the increase being at the expense of beds belonging to the Allegheny formation, as the Ferriferous limestone is but 17 feet above the Homewood. The lower sandstones at this locality have thickened greatly, but at the expense of the shales, as the total thickness is nearly the same.

Allegheny county is south from Butler, with southern Beaver at the west and Westmoreland at the east. In the northwestern part of the county, near the Beaver border, two records from wells barely a mile apart give

	Feet.	Feet
Homewood sandstone	17	12
Mercer group	31	32
Upper Connoquenessing	34	61
Quakertown shales	63	50
Sandstone	246	240

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*J. F. Carll: Ann. Rep. 2d Geol. Surv. Penn. for 1886, pp. 648, 649, 650.

in which the bottom sandstone is mostly Logan, as appears from the succession somewhat farther south toward Allegheny, which shows

	Feet
Homewood sandstone	60
Not named	20
Coal bed, Tionesta [?]	2
Shale	63
Sandstone	35
Sandy shale	45
Sandstone	52
Shale	15
Sandstone	48

resting on the Tuscumbia (Silicious) limestone, which has made its appearance in the interval. The Mercer group is not less than 63 feet, the Connoquenessing is 132 feet, and the Sharon sandstone appears to be again in the section.*

A very notable change takes place at a little way south on the Monongahela, where one finds

	Feet
Homewood sandstone	45
Shales, sandstones, and a *coal bed*	73
Sandstone	42
Sandy shales and a *coal bed*	33
Sandstone and shale	7
Sandy shale with *coal*	7

resting on the Lower Carboniferous limestone. The Homewood, Mercer, and Upper Connoquenessing are distinct, but both Lower Connoquenessing and Sharon are absent, for the lower part of the section has the characteristics of the Quakertown. The Ferriferous limestone of the Allegheny formation is 55 feet above the Homewood.†

Eastward from the Allegheny and Monongahela rivers one finds important records in Westmoreland and Fayette. In the extreme northwest corner of Westmoreland, not far from the last locality in southeastern Butler, the record is

	Feet
Homewood, white sandstone	100
Shales	35
Sandstones—gray, red, white	120
Shales	50
Coal bed	7
Shales	40
Sandstone	178

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*J. F. Carll: Seventh report on the oil and gas fields of Western Pennsylvania (I 5), 1890, pp. 152, 234, 239, 252, 253, 254, 255.

†J. F. Carll: 1886 report, p. 652.

Above the white Homewood are 65 feet of gray sandstone, extending to the Ferriferous limestone. The coal bed of the record is evidently the Sharon, and the bottom of the Pottsville is just below it, as the shales are Shenango and the sandstone Logan. The condition is similar at Murraysville, 10 miles farther south, where the succession is

	Feet
Homewood sandstone	55
Mercer shales	20
Upper Connoquenessing	75
Quakertown shales with sandstone and coal	20
Lower Connoquenessing	50
Sandy shales	30

to the Lower Carboniferous limestone which has made its appearance in the interval. The bottom shales are very black in the upper 10 feet, which may be taken as representing the Sharon coal bed, thus giving for the thickness of Pottsville 230 feet. No trace of the Tionesta or Mercer coals appears in the record. This record is of especial interest, as it is about one-third of the way eastward from Pittsburg to the Conemaugh gap, where only the upper part of the section is present.

Five or 6 miles farther south in Westmoreland county the record is

	Feet
Homewood	85
Mercer shales and "shells"	80
Upper Connoquenessing	40
Coal bed, Quakertown horizon	4
Sandstone and shale	55

resting on 85 feet of "Buttermilk sand," evidently the limestone. The Homewood has increased at expense of the overlying rocks, while the Connoquenessing sands are decreasing. The change continues southward for 6 or 7 miles farther. The record is

	Feet
Homewood	135
Mercer shale, black	30
Upper Connoquenessing, white	30
Quakertown shale, black	25
Lower Connoquenessing, white	20
Sharon shale, black	15

giving only 120 feet as total thickness of Pottsville below the Homewood. At barely a mile away the Homewood is but 48 feet, and the Connoquenessing sandstones have come together with a thickness of 80 feet.

A record in southern Fayette, within 8 miles of the West Virginia line, shows the same conditions, but exaggerated, for the Homewood is 160 feet thick and begins at only 848 feet below the Pittsburg coal bed, so that it includes some of the Allegheny beds as well as the Mercer and Upper Connoquenessing. A coal bed reported from this boring is evidently at the Quakertown horizon.*

The records in Washington and Greene counties, lying between the Monongahela river and the northern "Panhandle" of West Virginia, give much of interest. At Mount Pleasant, in northeast Washington, the succession is

	Feet
Sandstone	24
Shales	22
Sandstone	16
Shales	25
Sandstone	32
Dark shale	10

in all only 129 feet, and no trace of coals appears in the record. This is about 10 miles southwestward from the Monongahela locality, near Pittsburg. Compared with that, this shows a notable thinning in the upper part of the section. The Upper Connoquenessing is 72 feet thick at McDonald's station, 4 or 5 miles north from Mount Pleasant, where the other members of the section have very nearly the same thickness as given above. Here the Tionesta and Quakertown horizons are marked by black shale.†

The record at Washington, about 10 miles south from Mount Pleasant, is

	Feet.	Inches
Homewood	87	
Coal bed, Tionesta horizon	1	6
Upper Connoquenessing	81	6
Shales	93	

to the Lower Carboniferous limestone. Here the Homewood is at but 5 feet from the Ferriferous limestone, though the interval at Mount Pleasant is 111 feet, so that the increase is at the expense of the Allegheny beds; the Connoquenessing has increased at the expense of the Mercer shales, while the lower beds have lost their characteristics, and at best must be very thin, for much of the bottom shales must belong to the Shenango.

At Waynesburg, in Greene county, somewhat more than 20 miles south from Washington, the record is

	Feet
Homewood sandstone	65
Mercer shale	35

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*J. F. Carll: Report (1 5), pp. 213, 219, 225, 322.

†I. C. White: West Virginia Geological Survey, vol. i, 1899, pp. 218, 219.

resting on 20 feet of red rock, separating the shale from the underlying limestone, and the Ferriferous limestone is but 75 feet above the Homewood. Here all the members below the Mercer shale have disappeared.*

The records show a strange condition east from Waynesburg, toward the Monongahela river, for at 2 miles northeast from Waynesburg one finds 175 feet of sandstone, beginning at 900 feet below the Pittsburg coal bed, whereas at 2 miles east from Waynesburg there is nothing but shale in that interval, the Lower Carboniferous limestone being reached at 1,107 feet below the Pittsburg; but at 5 miles east from Waynesburg the sandstone begins at 607 feet below that coal bed and continues to the limestone at 1,135 feet, giving a sandstone mass of 528 feet, while at Carmichaels, 4 miles southeast from the last and little more than a mile from the Monongahela, the sandstone begins at 691 feet below the coal, thus:

	Feet
Sandstone	165
Shale and "shells"	35
Sandstone	180

in all 380 feet, separated by 10 feet of red rock from the limestone below. The Pottsville is in the bottom sandstone. The same sandstone is found at Willow Tree, about 12 miles southeast from Waynesburg, where, beginning at 840 feet below the Pittsburg, the succession is

	Feet
Sandstone	50
Shale	35
Sandstone	90

with 145 feet of red rock below to the place of the limestone at 1,160 feet. The lower sandstone is the Pottsville. The record at the West Virginia line, about 8 miles south-southwest from the last, beginning at 892 feet below the Pittsburg, is

	Feet
Sandstone	55
Shale and sandstone	85

with 110 feet of "white sandstone, red rock, and limestone" underlying it.†

NORTHERN AND WESTERN OUTCROP IN OHIO

Mahoning county, of Ohio, adjoins Lawrence, of Pennsylvania. Professor J. S. Newberry studied it during the second geological survey of the state, and, at a somewhat later date, Dr I. C. White followed the Pennsylvania section into the county, so that the relations are now sufficiently clear. The Homewood sandstone quickly becomes obscure west from the state line, but the Mercer group is characteristic throughout, both of the limestones as well as the coal beds being present at Lowellville, where the Tionesta coal bed is shown at from 2 to 10 feet above the Upper Mercer limestone. The Mercer group is about 70 feet thick. The Sharon coal bed appears about 2 miles farther up the Mahoning river, and thence in this as well as in the adjoining counties it occurs with its accustomed irregularity and uncertainty. The Ferriferous limestone, so important as a guide in Pennsylvania, disappears soon after crossing the state line, but its office is assumed by a new limestone, very near the bottom of the Allegheny formation, the Putnam Hill or gray limestone, which overlies a coal bed thought by Professor Orton to be the Brookville of the Pennsylvania column. This limestone first appears near Youngstown, a few miles west from the state line, where it is 2 feet 7 inches thick and 36 feet above the Upper Mercer limestone.

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*J. F. Carll: 1886 Report, pp. 650, 658.

†J. F. Carll: Report (I 5), pp. 312, 313, 314, 315, 316, 317. Mr Carll must not be held responsible for the identifications presented in the records quoted from his reports, as the writer has made them on his own responsibility.

The Connoquenessing sandstones, termed by Newberry the Massillon (which name is retained in the later Ohio reports by Orton), appear in White's sections as well as in those by Newberry, and are persistent in this county, though, as in Pennsylvania, they are variable. Doctor Newberry's Youngstown section shows them distinct, yet in the Foster shaft there they are one, with a thickness of 146 feet. Evidently several valleys existed in this immediate neighborhood at one time during the Pottsville, for at a mile east from Youngstown there are barely 11 feet of sandstone in the whole Connoquenessing interval, while in another shaft, a mile farther southeast, the sandstone is 80 feet. A similar condition exists near Austintown, west from Youngstown, where one shaft shows the sandstone continuous and 120 feet thick, whereas in most of the others the sandstones are distinct and separated by the Quakertown shale. The Quakertown coal bed seems to be persistent at 50 to 80 feet above the Sharon, except where cut out by the overlying sandstone. The Connoquenessing sandstone often replaces the Sharon shales, and at times even the coal bed itself. There is little trace of the Sharon sandstone in this county. The peculiarities of the Sharon coal and of its occurrence have been described well by Doctor Newberry, and they will be discussed in another connection.*

The Pottsville extends northward into the southern part of Trumbull county, where the exposed section reaches to the blue or Lower Mercer limestone. The Lower Mercer coal bed (number 3 of the Ohio section) is wanting. The Connoquenessing sandstones are present, but the upper one tends to become shaly. The Quakertown and Sharon coal beds are present, and the Sharon sandstone makes its appearance with an extreme thickness of 15 feet;* but this rock must increase rapidly in the west and northwest, for in Portage county, west from Trumbull and Mahoning, Newberry finds it 175 feet thick in the northeast corner, barely 5 miles from the Trumbull line and not more than 15 miles northwest from Mr Read's locality; yet the thickness must be less in the westerly part of the county, for the general section gives it as only 100 feet. The rock is a coarse drab sandstone, with portions consisting of quartz pebbles varying in size from a pea to a hen's egg. The thickness decreases very quickly southward, for the rock is absent in the southeastern part of the county at not more than 8 miles from northwest Mahoning. Northward beyond Portage the Sharon sandstone extends into Lake and Geauga counties, reaching to within 10 miles of lake Erie, retaining its characteristic features and apparently losing neither thickness nor coarseness.

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* J. S. Newberry: Report of the Geol. Survey of Ohio, vol. iii, 1878, pp. 784–795, 800, 803, 804, 805. I. C. White: (Q 2), pp. 219–224, 288.

The general section of Portage county, as given by Doctor Newberry, shows that the Putnam Hill or gray limestone is a constant feature. It represents that limestone as from 28 to 54 feet above the blue or Lower Mercer limestone. As no reference is made anywhere to the Upper Mercer limestone, it is possible that it and the Putnam Hill have been confounded at some localities, the more so because the two beds are much alike in all respects at many localities. As in Mahoning county, the Homewood sandstone is no longer well marked, and it is represented ordinarily by shale. Whether or not the Tionesta horizon shows any coal in Portage county can not be said, as no detailed sections are given. The Lower Mercer coal bed is reported as occurring at from 150 to 200 feet above the Sharon coal bed. In the southern part of the county, within 3 miles of the northwest corner of Stark county, a thin coal bed, unaccompanied by limestone, was seen at 20 feet above the Lower Mercer. The conditions in Stark county lead one to believe that this is the Upper Mercer. The Upper Connoquenessing is sometimes conglomerate, but in many places it is shaly, and as a whole it is less persistent than the Lower Connoquenessing, which is apparently the original Massillon of Newberry, though afterwards that term was applied to both divisions. The Quakertown coal bed is thin, but persistent, though at times replaced by the overlying sandstone. The Sharon coal bed is as irregular as in the other counties, though the little basins in which it was deposited are larger than those in Mahoning county.†

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* M. C. Read: Ohio Survey, vol. i, 1873, pp. 496, 498, 500, 502.

† J. S. Newberry: Vol. iii, pp. 137, 142, 143, 144, 145, 146.
M. C. Read: Vol. i, pp. 521, 522, for Geauga county.

In Summit county, west from Portage, the Sharon sandstone is said to be about 100 feet thick, becoming toward the bottom a mass of quartz pebbles, with just enough sand to hold them together; but these are coarser than in Portage, varying in size from that of a hickory nut to that of a man's fist. The ordinary irregularity of the Sharon coal bed is increased by inroads of the Connoquenessing sandstone, whereby it has been removed in many places. The Lower Mercer coal bed with its Blue limestone is from 130 to 160 feet above the Sharon, and the Putnam Hill limestone is from 25 to 40 feet higher. The report on this county deals almost wholly with economic descriptions of the several coal beds, and no local sections are given. The Homewood sandstone is as indefinite as in Portage.*

A small area of Pottsville remains in Medina county, northwest from Summit, and shows the Sharon sandstone about 130 feet thick, a coarse sandstone with some pebbles; but these, in contrast with the Summit County conditions, are for the most part very small. The Connoquenessing sandstone in the southwest corner of the county appears to be but 40 feet thick, separated by 48 feet of shale from the Sharon or Brier Hill coal bed, which at the locality described is 5 feet thick.†

Evidently the Sharon sandstone decreases rapidly toward southern Summit, for in Stark county, south from Summit and Portage, it is but 20 to 50 feet thick. The Sharon coal bed in this county is extremely irregular in occurrence, and has become variable in quality as well as in quantity, though in one portion its excellence is typical, and the bed is of great economical importance, so that it was named by Newberry the Massillon coal bed. The Connoquenessing (Massillon) sandstones are distinctly such in the Canton boring, as well as in many others; but the Upper is less persistent as a sandstone than is the Lower.

The Quakertown coal bed is commonly present and is known as the "fifteen-inch bed," though rarely exceeding 1 foot, and the interval to the Sharon is given as from 50 to 80 feet. A thin coal bed often underlies the Lower sandstone, almost always where the Sharon shale has not been cut out by the sandstone. One of Professor Orton's records shows that the cutting during or prior to the deposition of the sandstone must have been very deep. The Lower Mercer limestone and coal bed are persistent, though the coal is rarely of any value. The Upper limestone and coal bed are here but evidently very irregular in occurrence, for Newberry gives the interval from the Putnam Hill to the Lower limestone as 20 to 50 feet of shale and sandstone "sometimes containing a local coal and limestone." A boring at Alliance, in the northeast corner, adjoining Columbiana county, shows two coal beds, very thin, at 11 and 26 feet below the Gray limestone, which are evidently the Tionesta and the Upper Mercer, while at Magnolia, on the southern border of the county, a boring shows at 27 feet below the Gray limestone 2 feet 4 inches of limestone overlying 1 foot of coal, clearly the Upper Mercer. Professor Orton gives a section showing the Tionesta and the Mercer coal beds at 6, 15, and 57 feet below the Putnam Hill or Gray limestone coal bed, with both of the Mercer limestones present. The Homewood is not recognizable and its place is filled with shale or fireclay.*

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*J. S. Newberry: Vol. i, pp. 212, 213, 214, 217, 218.

†A. W. Wheat: Vol. iii, pp. 363, 378.

In Medina county, according to Mr Wheat, the Sharon sandstone is 130 feet thick; but in Wayne, south from Medina and west from Stark, it has become so insignificant that Mr Read practically ignores it, considering the petty local accumulations as merely material from the Waverly hills which bounded the irregular valleys in which the Sharon coal bed was deposited. In Stark county the least interval between the Sharon coal bed and the Zoar or Lower Mercer limestone is given by Newberry as 130 feet, but Mr Read gives the extreme interval in Wayne county as only 60 feet—a statement confirmed by the observations of Professor Wright in Holmes county, as well as by Mr Read's measurements in Knox county. The interval diminishes, according to Mr Read, so rapidly that at a few miles west from the line of Stark county and almost on the Knox border it is only 32 feet. The Connoquenessing, though often sandstone, is replaced by shale in much of this county. Traces of the Quakertown coal bed were seen occasionally, but the Lower Mercer is persistent, while the Upper Mercer, at a few feet above the Lower Mercer limestone, becomes important locally as a 5-foot bed of very fair cannel.†

In the northwestern corner of Tuscarawas county, south from Stark, Professor Orton finds this succession:

	Feet.	Inches
1. Putnam Hill limestone and *coal bed*		
2. Shale	30	0
3. *Coal bed*	3	0
4. Shale	10	0
5. Limestone, gray or blue	2	6
6. Fireclay and shale	23	0
7. Blue limestone	6	0
8. *Coal* and shale	7	9
9. Fireclay and shale	30	0

Here are the Tionesta and Lower Mercer coals, with both of the Mercer limestones. This locality is about 10 miles from Magnolia, in Stark county. The three coals and both limestones are present in the southwest portion of Tuscarawas, as well as near Zoar, toward the center. The Tionesta alone becomes of workable thickness, yielding a coal remarkably high in volatile, with a ratio of almost 1, but with so much ash as to make it of little commercial value. The Lower Mercer limestone is persistent, being present in borings on both sides of the county, but the upper limestone is of uncertain occurrence. The Sharon coal bed is persistent, after its fashion, but the Sharon sandstone is conglomerate only on the western side, where its extreme thickness is about 9 feet.*

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* J. S. Newberry: Vol. iii, pp. 155, 159, 165, 166, 170, 172, 173.
E. Orton: Vol. v, 1884, pp. 231, 811.

† M. C. Read: Vol. iii, pp. 525, 531, 533, 537.

In Holmes county, south from Wayne and west from Tuscarawas, the typical section of western Pennsylvania reappears, for Professor Wright gives the following succession :

		Feet
1.	Putnam Hill limestone and *coal bed*	
2.	Sandstone and shale	20
3.	*Coal bed* [*Tionesta*]	
4.	Shaly sandstone	20
5.	Upper Mercer limestone	
6.	*Upper Mercer coal bed*	
7.	Shales	30
8.	Lower Mercer limestone, blue	
9.	*Lower Mercer coal bed*	
10.	Shales	22
11.	*Coal bed*	
12.	Massillon sandstone, upper	38
13.	*Quakertown coal bed*	
14.	Massillon sandstone, lower, and shale	38
15.	*Sharon coal bed*	

For the most part the Sharon coal bed rests directly on the Lower Carboniferous, the Sharon sandstone being absent; but Mr Read found that sandstone in the northern townships of this county, where it has an extreme thickness of 18 feet. In the northeastern portion it contains broken angular fragments of white and yellow chert, with a profusion of fossils, which Mr Meek recognized as Lower Carboniferous. Small fragments of precisely similar material, according to Mr Read, occur at the Nelson ledges, in northeastern Portage, and at Boston, in northern Summit, mingled at the latter place with large angular and flat rock fragments. In the northern localities these fragments are at the bottom of the great mass.

The Sharon coal bed is as irregular as in the more northern counties, sometimes reaching 4 feet, but often wanting. The interval to the Lower Mercer coal bed varies from 80 to 100 feet, whereas in Stark and Mahoning it is from 130 to 160 feet. The coal bed resting on the Upper Connoquenessing (Massillon) sandstone is not present at all exposures, but the Quakertown, though always very thin, is rarely absent. The Connoquenessing (Massillon) sandstones are variable, and a thin coal bed was seen occasionally in the shales of the lower sandstone. The limestones and coals of the Mercer group appear in almost all of the sections, and the lower coal bed is almost as important commercially as is the Sharon. It yields a semi-cannel or block coal of good quality. The Upper Mercer is the Strawbridge cannel of Holmes county, with thickness of from 2 to 9 feet. The Tionesta coal bed is of workable thickness only near the Wayne county line, where it is from 3 to 4 feet thick. The Homewood, Tionesta of the later Ohio reports, is largely sandstone at many localities within this county. The whole thickness of Pottsville in the northern part of Holmes county is but 166 feet.[*]

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* J. S. Newberry: Vol. iii, pp. 56, 58.
E. Orton : Vol. v, pp. 67, 76, 259.

A small area of Pottsville remains in Ashland county, west from Holmes, where the Sharon sandstone is represented by 20 feet of shale containing locally 10 feet of conglomerate. In the isolated patches crowning several hills in southeast Richland, just west from the Ashland line, Mr Read discovered the same kind of chert fragments as in the Sharon of Holmes county.[†]

Coshocton county is south from Holmes and west from Tuscarawas. Mr Hodge found the Sharon sandstone in the northern part of the county, where it is 2 to 3 feet thick and contains fragments of chert, from one of which he obtained a fine crystal of galenite. The Sharon coal bed is as in the counties already described. Professor Edward Orton, Jr., obtained the following section on the western edge of the county:

	Feet
1. Putnam Hill limestone and *coal bed*	
2. Interval	17
3. *Upper Mercer coal bed*	
4. Interval	15
5. Lower Mercer limestone	
6. *Lower Mercer coal bed*	
7. Shales and shaly sandstone	48
8. Sandstone	50

to the place of the Sharon coal bed, thus giving for the formation, with all of the members recognizable, only 130 feet. A section obtained in the same township by Mr Hodge gives the interval from the Sharon coal bed to the Upper Mercer coal bed as 119 feet. The Connoquenessing sandstones can be recognized wherever their place is exposed, but they show much variation. At one locality Mr Hodge found the whole interval between the Sharon coal bed and the Upper Mercer limestone, 130 feet, occupied by an almost continuous sandstone, but in most places the Upper sandstone is rather shaly. The Lower Mercer limestone is the notably persistent member of the formation and occasionally it carries chert; the Upper limestone is absent at some places, but not often, and it is accompanied by chert; its coal bed is a valuable cannel in two townships. The Homewood is represented by shale almost everywhere.*

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[*] M. C. Read: Vol. iii, p. 546.
A. A. Wright: Vol. v, pp. 818, 823, 837, 838, 841.

[†] M. C. Read: Vol. iii, pp. 316, 317, 523.

Small areas of Pottsville remain in Knox county, west from Coshocton. The extreme thickness of the Sharon sandstone does not exceed 15 feet. The general section in the eastern part of the county reaches to 235 feet above the Sharon coal bed as follows:

	Feet.	Inches
1. Concealed	115	
2. Sandstone, thin conglomerate near bottom	45	
3. *Coal bed*	2 to 1	6
4. Shale	45	
5. *Coal bed*		
6. Sandstone	30	
7. Shale	10	
9. *Coal bed*		

The Sharon, Quakertown, and Lower Mercer horizons are marked by coal; another bed exists at 60 feet above the Lower Mercer, which may be that associated with the Putnam Hill limestone, but the Mercer limestone as well as the Putnam Hill have disappeared. The cherty limestone occurring on some of the ridges at 100 feet above the highest coal bed represents the Allegheny limestone. The whole thickness of Pottsville does not exceed 140 feet.†

Muskingum county is south from Coshocton. Stevenson gives the following generalized section for the northern part of the county:

	Feet
1. Putnam Hill limestone and *coal bed*	
2. Sandstone and shale	21
3. Upper Mercer limestone	2 to 3
4. *Upper Mercer coal bed*	
5. Sandstone	10
6. Lower Mercer limestone	1
7. *Lower Mercer coal bed*	
8. Fireclay	

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*J. T. Hodge: Vol. iii, pp. 571, 575, 576, 581.
E. Orton, Jr.: Vol. v, pp. 844, 853, 854, 859.

† M. C. Read: Vol. iii, pp. 335, 336.

		Feet
9.	Sandstone	75
10.	*Quakertown coal bed*	
11.	Shale and sandstone	45 to 50
12.	*Sharon coal bed*	
13.	Shales	50
14.	Conglomerate	28

The notable feature in the lower portion of the section is the great increase of rock below the Sharon coal bed—an increase which in one form or another becomes more and more noteworthy farther south along the western outcrop in Ohio and throughout the whole field in the states beyond. The Sharon conglomerate shows most of the features observed farther north by other students, but Stevenson makes no reference to fragments of chert. The Sharon coal bed occasionally reaches 2 feet 6 inches, but is broken by clay partings into benches of dissimilar coals; but the occurrence of this bed is very uncertain; it is wanting at many places. The Connoquenessing sandstones are persistent, and the Quakertown coal bed is present in the northwest part of the county, though very thin. The interval of 120 feet between the Sharon coal bed and the Lower Mercer is the extreme. The Mercer coal beds are present in every section where the horizon is exposed but, except in the southwest corner of the county, they are insignificant. No trace of the Tionesta coal bed was observed and the Homewood is never more than a shaly sandstone. The close resemblance of this section to that of Lawrence county, Pennsylvania, is important, for all members of the formation are here with much the same features as in the typical section. This Muskingum section was made in 1872.*

Before following the western outcrop farther toward the south, it may be well to refer briefly to counties lying eastward toward the Ohio river, where for the most part the Pottsville is under cover.

Columbiana county is south from Mahoning along the Pennsylvania border. Doctor White's sections in the northeastern part of the county show the Upper Mercer limestone represented by chert at many localities along the western outcrop. A thin coal bed, at one place, rests on the Upper Connoquenessing.

Professor Newberry reports two coal beds in a boring midway along the northern border which are at the proper places for the Mercer coals. Borings somewhat farther south reach the Lower Mercer and show both coals at 31 and 63 feet below the Putnam Hill limestone, but the Mercer limestones are wanting, as they are also at the more northern locality.†

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*J. J. Stevenson: Vol. iii, pp. 239, 243.

†I. C. White: (Q 2), pp. 268-272. J. S. Newberry: Vol. iii, p. 110. E. Orton: Vol. v, p. 37.

An oil-well record in northern Jefferson, south from Columbiana, shows two coal beds at 111 and 150 feet below the Lower Kittanning coal bed, which evidently are the Mercer coals, but the Mercer limestones are missing.*

An oil-well record in West Virginia opposite Steubenville, Ohio, shows neither coal nor limestone in the Pottsville, unless the coaly matter at the bottom be taken as representing the Sharon coal bed. There, as at Steubenville, the Pottsville is a massive sandstone. Borings in Belmont county, south from Jefferson along the Ohio, show a somewhat similar condition, for in the 350 feet above the Lower Carboniferous there is only sandstone broken just above the middle by 30 feet of shale. It is clear that the coals and limestones are lacking in eastern Jefferson and Belmont counties as well as in a great part of Columbiana.†

Unfortunately there are no data available now for Harrison county, west from Jefferson and north from Belmont, but Stevenson reports some records of borings in Carroll county, north from Harrison, which show a limestone and coal bed at from 18 to 45 feet below the coal bed underlying the Putnam Hill limestone. The limestone is the Upper Mercer. The same observer states that the Upper Mercer limestone is reached in exposed sections within Guernsey county, between Belmont and Muskingum, and that the underlying coal is a cannel; but at Cambridge, in the central part of the county, a well record shows no trace of coal or limestone in 365 feet above the Lower Carboniferous, while in the eastern part of the county the first trace of coal is at 220 feet above the Lower Carboniferous. This underlies a fossiliferous black shale which may represent a limestone, perhaps the Putnam Hill.‡

Returning now to the west and passing southward from the Ohio Central railroad, one finds in the central part of Muskingum county a measurement by Professor Orton which shows the intervals between the Putnam Hill limestone, the Lower Mercer, and the Sharon coal beds to be 80 and 70 feet.

The Pottsville extends in isolated patches westward beyond Muskingum almost half way across Licking county. There Mr Read found the Sharon sandstone represented by conglomerate sometimes 15 feet thick and containing angular fragments of chert such as those observed by him at more northerly localities. The Sharon coal bed is from 2 to 10 feet above it, and occasionally becomes 3 feet thick. At 2 miles northeast from Newark he found a bed of fireclay underlying a 4-foot bed of limestone and separated from the Sharon coal bed by 100 feet of sandstone, apparently the Lower Mercer limestone; but in the southeast corner of the county and extending into Muskingum he finds the "Flint Ridge cannel" under the same limestone, with occasionally a thin coal bed at from 25 to 35 feet below it.[*]

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*J. S. Newberry: Vol. iii, p. 741.

†E. Orton: Vol. vi, pp. 338, 405.

‡J. J. Stevenson: Vol. iii, pp. 195, 221. The measurements by this observer were made in 1871 and 1872, but not published until 1878. The Pennsylvania terms were not used in his reports. They have been applied here, as also in the extracts from reports of other members of the survey during its earlier years.

E. Orton: Vol. vi, pp. 378, 381.

In the general description of formations exposed within the Second Geological district, Professor Andrews says that on the border of the Hocking Valley coal field, embracing parts of Perry, Hocking, and Athens counties, he finds at 80 feet above the Maxville limestone a limestone with a thin coal bed under it; at 20 to 35 feet higher another, often flinty and also overlying a thin coal bed, while at 40 feet above the last he finds the Putnam Hill limestone. These are the Mercer limestones and coal beds. The Sharon coal bed, very thin, is at a few feet above the Maxville limestone, while another is seen occasionally at 20 feet higher, and a third, the Quakertown, at 58 feet.[†]

The Pottsville was followed by Professor Orton around the Hocking Valley field, supplementing the observations of Professor Andrews. The Tionesta coal bed is present in Perry county at about 10 feet above the Upper Mercer limestone, and at one locality is commercially important. That limestone is not always present, but its ore bed is so well characterized as to mark the horizon. The Lower Mercer limestone is thoroughly persistent. Its extent is shown on the map of the Hocking Valley coal fields accompanying volume vi, from which it appears that the bed, where spared by erosion, reaches to the extreme western outcrops of the coal field in Perry, Vinton, and Hocking counties, attaining at times, even on the western line, a thickness of 10 feet. A thin coal bed is often shown at 45 to 50 feet below it, which may be at the Quakertown horizon. The Sharon coal bed, from 80 to 120 feet below the limestone, is represented usually by coal or coaly shale, and is separated by a thin shale deposit from the Maxville limestone, though occasionally one finds an attenuated representative of the Sharon conglomerate.[‡]

The Lower Mercer limestone was traced by Professor Andrews across Hocking county, where it is commonly accompanied by its iron ore, the "Little block" and the Lower Mercer coal bed. In Athens county, east from Hocking, the limestone becomes very thin, being only 6 inches where last seen, and it evidently disappears within a short distance. The Sharon sandstone can not be recognized in Hocking or northern Vinton.*

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[*] M. C. Read: Vol. iii, p. 358.

[†] E. B. Andrews: Vol. iii, pp. 823, 824.

[‖] E. Orton: Vol. v, pp. 886, 905, 919, 989.

Passing from Hocking into Vinton county, the next south, one finds the border of Upper Carboniferous extending farther westward than in the northern counties; so that in Vinton it is almost on the western edge of the county, while farther south it passes out of Jackson into Pike county, where some isolated areas remain, fully 20 miles farther west than the western limit in Licking county.

At numerous places in Swan and Jackson, the northwest townships of Vinton county, as well as in northern Richland, adjoining Jackson township on the south, a coal bed 4 inches to 2 feet 10 inches thick is shown resting on the Waverly or separated from it by at most a few feet of fireclay. This is 120 feet below the Lower Mercer limestone and is the Sharon coal bed. The Sharon sandstone makes its appearance in the middle of Richland township, where a section shows the Sharon coal bed at 60 feet above the Logan and 15 feet above a massive sandstone, of which the bottom 12 feet is a hard white sandstone containing "concretions of flint and lime and made up largely of organic remains, forms often comminuted." Professor Andrews thinks these probably represent the Maxville, and he states that he has seen similar forms near Newark, in Licking county. This is the same white sandstone so often referred to by Mr Read in his descriptions of the northern counties, and the concretions are evidently the same with Read's irregular broken fragments, accompanied by angular fragments of rock.

Other measurements by Professor Andrews in the southern part of Vinton county make the matter wholly clear and prepare the student to understand the conditions in Jackson county which caused so much perplexity in the past. In southern Richland, Professor Andrews reports a section which makes the interval from the Lower Mercer limestone to the Waverly 189 feet, with the Quakertown coal bed at 75 feet below the limestone, and another coal bed, 3 feet 6 inches thick, within 15 feet of the Waverly, or about 170 feet below the limestone. This was very perplexing to one who so zealously championed the doctrine of parallelism of coal beds, but he states that the measurement is open to no doubt, as it was made repeatedly by the aid of the Locke's level. It shows, he says, a thickening of the interval between the (Mercer) limestone and the Waverly of 60 feet in a southwest direction within three miles and a half. At an exposure within a mile he finds a coal bed, 13 inches thick and of excellent quality, at 60 feet above the Logan or 110 to 120 feet below the limestone. This is the Sharon coal bed, and the lower bed is at a new horizon, unknown as coal bearing thus far in our tracing through Pennsylvania, outside of the Anthracite strip, and Ohio; southward it becomes important, though the coal is not always present, having been replaced by the sandstone at many places.*

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*E. B. Andrews: Report for 1870, pp. 80, 82, 87.

According to Professor Orton, the Lower Mercer coal bed is more important in Vinton than elsewhere in Ohio except in Holmes county. Professor Andrews finds a variable coal bed at 4 feet above the Lower Mercer limestone in Elk and Richland townships which probably represents the Upper Mercer horizon. It does not appear in any others of his sections unless that at 18 in Clinton and that at 25 feet in Brown are the same bed. His sections show a fairly persistent bed at 34 to 37 feet above that limestone in Elk and Clinton, and Professor Orton refers to it as occurring in Madison. This is the Newland coal bed which Professor Orton is inclined to assign to the Tionesta horizon, where it certainly belongs, for the Brookville coal bed (of Orton) is present above it. The Lower Mercer limestone persists and at times is 10 feet thick even on the western outcrop.*

In western Vinton, one approaches once more the western margin of the Upper Carboniferous, for the coarse conglomerate reappears in Richland township, where Andrews found the Sharon coal bed at 60 feet above the Logan sandstone. Followed southwestwardly, the conglomerate increases rapidly, becoming 130 feet in the northwest corner of Jackson at a mile or two south from the Vinton line. Thence to the southern border of the county the outcrop trends southwardly and the thickness decreases, becoming only 80 feet in the other western townships. This conglomerate is often very coarse, with pebbles mostly of white quartz and as large as hens' eggs. The mass changes very quickly toward the east, being replaced in great part by sandstone and shale, and at the same time it becomes thinner.

The rapidity of this change is shown at one locality, where on one side of a narrow valley the conglomerate is 80 feet thick, whereas on the opposite side the upper 50 feet is replaced by shales and sandstones with a coal bed at the bottom or at 31 feet above the base of the conglomerate. Professor Orton has shown that in the northwest corner of the county this conglomerate contains coal beds.

The relation of this conglomerate to the other beds was a source of perplexity and the conclusions to which the several observers arrived were not wholly in accord. The condition beginning in southern Vinton and becoming so marked in Jackson is of such interest, in view of the further development of this portion of the section in more southern localities, that it is necessary to examine it with a degree of detail which may appear extreme.

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* E. B. Andrews: Report for 1870, pp 96, 97, 99, 100, 101, 102, 105.

† The reader, who may consult the reports of Professor Andrews for 1869 and 1870, should remember that in those reports the Blue limestone (Lower Mercer) is identified with the Putnam Hill limestone. This error was corrected by Professor Andrews in his later reports published in vol. i of the final volumes.

Professor Andrews has shown that the Lower Mercer limestone is persistent, and Professor Orton has shown in addition that the Upper Mercer horizon may be followed easily by means of its ore bed (the Franklin or Dunkel Block) even where the limestone is absent.

Professor Andrews says that in the southwest portion of Washington township, within 2 miles of the Pike county line, a coal bed 3 feet 2 inches thick is present at 120 to 125 feet below the Blue or Lower Mercer limestone, with the intervening rocks concealed, but at a little way south a coal bed was seen at 70 feet below the limestone. These are the Sharon and Quakertown beds of Vinton. The lower bed, the Sharon, is known as the Wellston coal. At 3 miles from the last locality he finds a third bed at 36 feet below the Wellston, the three beds being exposed in the hillside. The interval between the Wellston (Sharon) and the lower coal bed is filled in great part by coarse sandstone and conglomerate. This lowest bed is composed of laminated coal like that obtained from the shaft bed at Jackson, and rests on the irregular surface of a heavy white pebbly sandstone at 97 feet below the highest coal bed, and therefore at about 167 feet below the Lower Mercer limestone. In this (Lick) township, the middle coal bed, Sharon-Wellston, is exposed at 125 feet below the Blue limestone, while near by an exposure shows coals at 45 to 80 feet below the nearest exposure of the limestone; and at a little way south the bottom coal bed is seen again, resting on a massive white sandstone at least 40 feet thick. The least interval between the Blue (Lower Mercer) limestone and the Wellston coal is in the northeast part of the county, where it is 113 feet.

At Jackson, 8 miles south from the Vinton line and at an equal distance east from the Pike line, the lowest coal bed is reached by a shaft and is known as the "Jackson Shaft coal bed." Its floor is very undulating; in one part of the mine it dips 30 feet within a few rods. Professor Orton finds this shaft bed at 142 feet below the Lower Mercer limestone in a boring about a mile east of Jackson.*

The facts observed in Vinton and Jackson counties leave no room for

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*E. B. Andrews: Report for 1870, pp. 127, 132, 145, 148.
E. Orton: Vol. iii, p. 912; vol. v, pp. 1009, 1010, 1032.

doubt that the coal bed at 45 feet below the blue limestone is the same with that often seen just above the Upper Connoquenessing; that the bed at 70 to 80 feet is at the Quakertown horizon, and that the "Wellston coal bed" is the Sharon. The Jackson Shaft coal bed is within the Sharon conglomerate, and is the same with that discovered by Andrews in southern Vinton, representing a coal-making stage wholly without coal at any localities in the northern part of the basin, where the horizon is exposed frequently. The Wellston and Shaft coals are of excellent quality, and the former occasionally becomes cannel. As usual, the Sharon floor is irregular. The Mercer coals are unimportant, but the Tionesta is of workable thickness in the northeastern part of the county, where it is largely cannel, a characteristic which becomes more and more marked as the bed is followed southward.

In the report on Pike county, which is west from Jackson, Professor Orton joins the Jackson section to that of Pike. Three miles west from Jackson a 3-foot coal bed, identical in character with that of the Shaft coal bed, is worked. The same bed is mined at 2 miles northwest, as well as on the county line, which makes the junction with the mines of northeast Pike. There has been a great change in the Sharon sandstone within this interval. Professor Orton states that the Wellston coal bed is found at one place in northwest Jackson county at 125 feet above the lower coal bed. This shows a rapid increase in the upper Sharon, but he gives no measurements of the lower portion—that below the Shaft coal. The increase in this, however, is equally notable, for in northeastern Pike the Shaft coal bed is underlain by 180 feet of conglomerate and has overlying it 75 feet of sandstone and conglomerate to the top of the section. The Sharon (Wellston) coal bed is not reached in this county. It is evident that the western limit of the basin lay not far west from eastern Pike. The interval from the Sharon coal bed to the Waverly, in Lick township of Jackson, is not more than 60 feet; in eastern Jackson township it is 130 feet, while in the northeastern part of Pike it is not less than 310 feet, taking the interval above the Shaft coal as continuing unchanged into Pike; but the increase in the upper portion was the more notable in Jackson, so that the total in Pike may not have been less than 400 feet. The coal becomes uncertain in occurrence within Pike and runs out within 3 or 4 miles west from the Jackson line, for exposures of its place there show no trace of the coal.*

Professor Andrews states that the conglomerate reaches only into the northwest corner of Scioto county, south from Jackson. There it is 80 feet thick, but followed southward it loses coarseness, though its equivalent in shales and sandstones remains; for at 4 or 5 miles south from the southwest corner of Jackson he found the interval from Blue or Lower Mercer limestone to the Logan 194 feet, and a section near by shows the Quakertown and a sub-Sharon coal at 68 and 176 feet below the limestone, with much sandstone in the partially exposed interval above the lower coal. This lower portion is persistent westward to the outcrop, for the "Guinea Fowl" ore at 30 to 40 feet from the bottom persists to the western outcrop in this county, which, however, is much east from the western limit of the basin.

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* E. Orton: Vol. v, p. 1009; vol. vi, pp. 615, 631, 632, 635.

The Franklin, "Main," or "Big Red block" ore, marking the horizon of the Upper Mercer limestone, is present at 105 feet below the Ferriferous limestone, and at 24 feet lower is the "Little Red block" ore representing the Lower Mercer limestone. Professor Andrews reports the lower limestone in Vernon township with a thin coal below it. Professor Orton says that the Tionesta, lying above the Franklin ore, is fairly persistent, but is represented ordinarily only by streaks of coal distributed through 10 to 20 feet of shale, though occasionally it becomes concentrated so as to be of workable thickness.

Doctor White reports a section obtained by himself at Hanging Rock, in the southern part of the county, which must be given without change:

	Feet.	Inches
1. Massive sandstone	40	0
2. Fireclay	5	0
3. Limestone and ore, Upper Mercer	1	0
4. Shales	20	0
5. *Upper Mercer coal bed*	0	4
6. Sandy fireclay, shale, and sandstone	18	0
7. *Lower Mercer coal bed* and clay	3	1
8. Fireclay and shale	5	0
9. Upper Connoquenessing sandstone	30	0
10. Sandy shales and sandstones	15	0
11. *Quakertown coal bed*	2	1
12. Fireclay and sandy shale	20	0
13. Lower Connoquenessing sandstone, massive	25	0
14. Shales	40	0

to which must be added 40 feet to the bottom of the Pottsville, as shown in a well record at Hanging Rock. This is on the Ohio river, several miles below the mouth of the Little Sandy river, in Kentucky. The lower or Sharon sandstone portion of the column has disappeared.

The section exposed in Lawrence county, east from Scioto, extends downward only to the Tionesta, which is known here and in northern Kentucky as the "Hunnewell cannel." An oil-well record at Ironton, on the Ohio, a few miles below Hanging Rock, shows the Quakertown coal bed, very thin, at 79 feet below the surface, which is very near the level of the Upper Mercer horizon. Below this coal there are only blue shales for 203 feet, with 8 feet of conglomerate at 112 feet and 10 feet of sandstone at 150 feet. Underlying the shales is a mass of sandstone and conglomerate, which Professor Orton was inclined to regard as representing both the Lower Pottsville and the Logan; but in view of the conditions at Hanging Rock and those soon to be mentioned in Kentucky, it is safer to regard the 8 feet of conglomerate as the Sharon sandstone and the bottom of the Pottsville.

Other counties along the Ohio river will be referred to in another connection.*

KENTUCKY

Passing over into Kentucky, one finds the Main or Franklin iron ore, which is at or very near the horizon of the Upper Mercer limestone, persisting in the northern part of the state, where it is from 85 to 100 feet below the Ferriferous limestone, which is traceable for more than half the distance to the Tennessee line. In studying the variations of the Pottsville within Kentucky, it is best to follow the western outcrop, where for the most part one finds the lower part of the section, and afterward to take up the counties eastward to the line of Virginia and West Virginia, in which the upper part of the section is shown, with occasional exposures of the lower part where that has been brought up by folds or faults.

Greenup county adjoins Scioto and Lawrence of Ohio and is north from Carter county. Professor Crandall's generalized section for these counties is as follows, the identifications with Ohio beds being inserted by the writer:

		Feet
1.	*Coal bed 5*	
2.	Homewood sandstone [Homewood]	37
3.	*Coal bed 4* [*Tionesta*]	
4.	Shales and Block ore [Main]	8
5.	Sandstone	29
6.	*Coal bed 3* [Mercer]	
7.	Sandstone [Upper Connoquenessing]	112
8.	*Coal bed 2* [Quakertown]	
9.	Sandstone [Lower Connoquenessing]	35
10.	Shale [Sharon]	40
11.	*Coal bed 1* [*Sharon, Wellston*]	
12.	Shales	33

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* E. B. Andrews: On Scioto County, Report for 1870, pp. 163, 166, 167, 168, 173, 175, 176.
E. Orton: Scioto, vol. v, pp. 1040, 1042. Lawrence, vi, p. 305.
I. C. White: Bull. U. S. Geol. Survey, no. 65, p. 193.

	Feet
13. Conglomerate, coarse sandstone [Sharon]	100 to 0
14. Shale and non-plastic clay [Sciotoville]	19
15. *Coal bed* [*Jackson shaft*]	
16. Shale	8

to the Waverly or, where present, to the Lower Carboniferous limestone. The Upper Mercer coal bed appears to be unrepresented, "Coal bed number 3" being clearly the Lower Mercer. It will be referred to in succeeding pages as the Mercer coal bed.

The lowest coal bed, that at the horizon of the Jackson Shaft bed, is of somewhat uncertain occurrence, as the overlying sandstone frequently replaces it as well as a portion of the underlying beds. It is present along the Ohio river at some localities in western Greenup, and is seen occasionally in western Carter. Mr Lesley says that it is exposed frequently in the latter county along streams entering Little Sandy river from the west. Its thickness varies from 1 to 28 inches, and it is seldom of economic importance even locally, though its coal, like that at Jackson, Ohio, is usually of excellent quality. The Sciotoville clay overlying it was seen at many places along the Ohio, and it was observed at localities in western Carter, even to the southwest corner on the Rowan county line.

The interval to the Sharon coal bed above shows extreme variation. The Sharon conglomerate is practically absent in much of northern Greenup or is represented at most by a thin sandstone overlying the Sciotoville clay. Throughout western Greenup it is comparatively thin, seldom more than 30 feet, until toward the southern border, where an exposure shows it 90 feet thick. There is a narrow area in western Carter where this conglomerate seems to be wanting, but in central Carter, the space drained by Tygarts creek and the Little Sandy, it is thick—30 feet in the northern part of the county and increasing to 90 feet or more near the southern border. In like manner it increases westwardly from the area of vacancy, for Lesley found it 150 feet thick in Rowan county west from Carter. Crandall describes this Sharon as a very coarse ferruginous sandstone, with some layers of quartz-pebble conglomerate. It is much cross-bedded and the inclination of this bedding is very uniformly toward the southeast—a condition observed in all exposures across Lawrence county to the West Virginia line.

Beds overlying the Sharon are reached occasionally in the high hills of western Greenup and Carter, especially where that sandstone is very thin, but satisfactory sections for the most part were obtained only eastward from Tygarts creek. In northern Carter the Main Block ore is at

120 and 185 feet above the Quakertown and Sharon coals respectively and 330 feet above the Lower Carboniferous limestone; but in northern Greenup and southwestern Carter, where the Sharon sandstone is absent or very thin, the Sharon coal bed is but 44 to 60 feet above the limestone.

Near the mouth of the Little Sandy river, on the Ohio, the Quakertown coal bed is shown between the Connoquenessing sandstones at 76 feet above the Sharon coal, and at 44 feet below the latter is the Jackson Shaft coal underlying the Sciotoville clay. At a few miles south, on the west side of the river, the section exhibits the Main Block ore, with below it the Mercer coal bed at 35 feet, the Quakertown at 112 feet, and the Sharon at 189 feet, the Quakertown being double, with 8 feet of sandstone and shale between its "splits," so that the interval from the lower split to the Sharon coal is but 65 feet. As the Mercer coal is ordinarily double, Lesley called it the "Twin coal." The Lower Block ore of this region is not the same with that of Ohio, being in the Lower Connoquenessing sandstone. "Coal number 4," of the Kentucky survey, here identified with the Tionesta, is the Hunnewell cannel of Greenup, as was recognized long ago by Professor Orton. It is prominent on several streams entering from the east and is at somewhat less than 100 feet below the Ferriferous limestone and 38 feet above the Mercer coal bed. The Mercer limestones are not in the section, but a thin, blue, silicious limestone is shown in one section of western Greenup at 145 feet above what seems to be the Sharon coal bed, and apparently the same limestone is shown in northern Carter, where the interval is 160 feet.

The interval between the Sharon and Mercer coals in northern Greenup is from 150 to 160 feet, but it increases southwardly, so that in northern Carter it is 180 to 231 feet. In southern Carter the Sharon and Quakertown are 90 feet apart and the latter is cannel. The Mercer is still double and in southern Carter one of the benches is cannel. The Tionesta is easily traced across Carter into Elliott, but it varies greatly in thickness and quality.*

In Elliott county, south from Carter and east from Rowan, the bottom of the Pottsville is reached on some branches of Little Sandy, and beds overlying the Sharon sandstone are shown in the highlands. At localities examined by Professor Crandall, the conglomerate replaces the lower beds and rests on the Lower Carboniferous. Mr Lesley reports the Jackson Shaft coal bed as present under the conglomerate on some large streams entering from the west. As in Carter, the Sharon is for the most part a coarse sandstone; it increases southward, for its cliffs on Little Sandy become 175 feet high, while above it is shaly sandstone passing into shale, in all 75 feet, on which rests the Sharon coal bed. How much of this upper rock should be regarded as Sharon is difficult to determine, but farther south it appears to be wholly separate and to have been deposited on an irregular surface of Sharon sandstone. The Sharon shale contains calcareous concretions already recognized at this horizon in Greenup and Carter, which characterize these shales in Lawrence county east from Carter, as well as in counties south from Elliott. The Quakertown coal bed, about 75 feet above the Sharon, retains its cannel in Elliott as it does southward and eastward in Morgan, Johnson, and other counties. The Mercer, at 163 feet above the Quakertown, or 240 feet above the Sharon, is an important bed and is mined at many places on the east side of the county, but on the westerly side it is broken by many partings and is less valuable. The Tionesta (Hunnewell) is very irregular, but is still the "upper cannel."*

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*Joseph Lesley: Fourth Report of the Geol. Survey of Kentucky, 1861, pp. 459, 460, 462, 463.

A. R. Crandall: Geol. Survey of Kentucky, Eastern Coal Field, vol. C, 1884, pp. 10, 29, 33, 36, 47, 48, 49, sections 1, 4, 5, 7, 8, 9, 19, 20. Vol. C is a reprint. Professor Crandall's report was published in Reports, new series, vol. ii. The intervals given in the text may not be altogether exact, as they were obtained by measurement of the diagrams. This remark applies to almost all measurements quoted from reports of the new series.

P. N. Moore: Geol. Survey of Kentucky, new series, vol. i, pl. 4, sec. 4.

Morgan county is south of Elliott and Rowan, with Menifee at the west. In its western portion the coal of the Jackson Shaft (?) horizon was mined by stripping many years ago and was highly prized for blacksmiths' use; it varied from 6 to 12 inches. Lesley found the Sharon sandstone 140 feet thick, with the Sharon coal bed above it. Professor Crandall says that the Sharon coal bed in northwestern Morgan is at about 50 feet above the Sharon sandstone, and the overlying shales contain calcareous bands and limestone concretions. Here, however, somewhat similar concretions, but much more sandy than those below, are associated with the Quakertown bed. The higher coal beds will be described in connection with the eastern counties. Professor Crandall gives the thickness of the sub-Sharon shales as from 10 to 50 feet and calls attention to cross-bedding of the sandstone.†

Menifee county is west from Morgan, southwest from Rowan. The section does not reach to the Sharon coal bed. In the southern portion, near the border of the basin, the Sharon sandstone becomes 200 feet thick and passes upward into a shaly sandstone as in Elliott. The underlying shale increases from 15 feet in the northern part of the county to 125 feet in the southern. The non-plastic Sciotoville clay is present, but its place was not ascertained, as only loose fragments were

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*Jos. Lesley: Fourth Report, pp. 462, 463.
A. R. Crandall: Geology of Elliott County, 1887 (?), pp. 6, 13-16.

†Jos. Lesley: Fourth Report, pp. 463, 465-466.
A. R. Crandall: Vol. vi, new series, p. 11, sec. 2.

seen on the surface. Where the shales are thickest they hold coal beds at 5, 55, 85, and 110 feet above the Lower Carboniferous limestone, the second bed being cannel. This great thickness continues southward into Powell county, where 100 feet are exposed on Indian creek.[*]

The Sharon sandstone is 175 feet thick in Bath county, northwest from Menifee. It is a coarse sandstone with some conglomerate cemented by iron ore. At the localities examined by Mr Linney the sub-Sharon shales are wanting, replaced by the sandstone which rests on the Lower Carboniferous; but Mr Lesley in crossing the southeast portion of the county found the shales 85 feet thick and underlying 100 feet of sandstone. Two coal beds were seen by him at 15 and 27 feet above the limestone.[†] The shales are thinner in eastern Montgomery, which is west from Menifee, for there Lesley found but 40 feet, with a coal bed at 4 feet above the limestone. The shales are thicker in Powell, south from Montgomery, for there they are 75 feet, while the Sharon sandstone has increased to 196 feet. In Estill county, south from Powell, the Sharon is 235 feet thick near the old furnace in the northern part of the county, where it rests on sandy shales and thin bedded sandstones with a thick fireclay at the bottom, below which is a coal bed associated with the iron ore of the Lower Carboniferous limestone.[‡]

Wolfe county is between Morgan at the northeast and Powell and Estill at the west. Mr Hodge describes the Sharon as consisting of two benches of sandstone containing quartz pebbles in greater or less profusion, separated by a shale deposit, the thickness of the whole approximating 200 feet. Underlying this is a mass of shale, 100 feet thick in the northwest, but thinning rapidly southward and eastward to 50 feet. The upper bench of the Sharon sandstone contains a great abundance of quartz pebbles, whereas the lower bench contains comparatively few. The pebbles diminish in quantity eastwardly on the north fork of the Kentucky river, so that where the rock is shown in Breathitt, east from Wolfe, it is almost free from them. The upper surface is very irregular and the overlying shales and sandstones filling the irregularities are of correspondingly variable thickness, so that the Sharon coal bed at times rests almost directly on the sandstone, while at a comparatively short distance it is separated from it by an interval of almost 100 feet. A section in western Wolfe on the Powell border shows

	Feet.	Inches
1. Shale	150	0
2. Conglomerate	115	0

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[*] A. R. Crandall: Vol. iv, new series, pp. 174, 177.

[†] Jos. Lesley: Fourth Report, p. 466.
W. M. Linney: Geology of Bath County (1886?), pp. 35, 36.

[‡] Jos. Lesley: Fourth Report, pp. 468, 469, 471, 530, 531.

	Feet.	Inches
3. Shale and clay with *coal* 5 inches	10	0
4. Conglomerate and shale	75	0
5. Shales	50	0
6. *Coal bed*	0	3
7. Shales	15	0
8. *Coal bed*	1	0
9. Shales	35	0
10. *Coal bed*		

to the Lower Carboniferous limestone. A coal bed is seen in the shales separating the plates of the conglomerate; another was found farther south in Clay county within 60 feet of the top of the conglomerate. These coals foreshadow the condition farther south, where coal beds within the Sharon sandstone become important. Mr Hodge finds two streaks of impure limestone here, one in Number 5 and another about 100 feet lower.*

Jackson and Rockcastle counties are in order southwest from Estill. The section evidently reaches only to the shaly sandstone overlying the Sharon sandstone. Mr Sullivan finds 8 coal beds in this lower portion of the Pottsville, which farther south has been designated the "Rockcastle group" by Professor Crandall; these are at 30, 45, 50–65, 75–95, 120–150, 185–200, and 225 feet above the Lower Carboniferous limestone, nearly all of which attain some importance locally. The main bed is that at about 60 feet as described by him and Mr Lesley. The whole thickness of this Rockcastle group is not far from 300 feet, the top portion being the coarse upper plate, evidently its upper portion, and the highest coal is very near the place of that observed by Mr Hodge in Clay county.

The increasing coarseness of the lower members of this Rockcastle group has become very distinct here. Mr Sullivan speaks of the coals as "interconglomerate," for in the intervals separating them are ledges of sandstone consisting largely of "hailstone grit." The important bed at about 60 feet above the limestone rests on a thick conglomerate ledge. The subconglomerate shales of more northern counties become replaced by sandstones near the border. The westward thinning of the measures observed in passing from Menifee into Montgomery is more sharply marked in Rockcastle, where the beds have spread apparently almost to the original border. Mr Sullivan says that in this county the thickness of the group varies from 45 to 250 feet. Mr Lesley gives the matter more in detail, for he says that the upper plate, 80 feet thick in southeast Rockcastle, is insignificant in the northwestern part of the county, while the lower portion decreases with equal rapidity, so that the whole thickness, 300 feet at the southeast, becomes, in successive measurements, 240, 102, and finally only 40 feet on the western border. Southeastward from Rockcastle it shows increase in Pulaski, and thence until the maximum is reached in Pine mountain of Bell and Whitely counties.*

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*G. M. Hodge: Preliminary Reports on the Southeast Kentucky Coal Field, 1887, pp. 95, 108, 109, sec. 92.

In Laurel county, south from Jackson, the Rockcastle group is shown with greatly increased thickness on a branch of the Cumberland river, but no information respecting this county is available beyond the statements that in northern Laurel, near Pittsburg, a boring found ten coal beds below the Laurel (Sharon) coal bed, and another near the Cumberland river found eight, all of them belonging to this group. In Pulaski, which is south from Rockcastle and west from Laurel, the rocks are shown at many places, especially in the eastern half of the county. In the western part Mr Lesley found the thickness, as in Rockcastle, not far from 300 feet and diminishing westwardly. The upper plate is about 80 feet, where thickest; in the lower portion, with an extreme thickness of 200 feet, he finds five beds of coal at 27, 80–93, 125, 150, and 175 feet, the last underlying the 80-foot ledge of conglomerate, a persistent coal-bearing horizon from its first appearance in Clay county for a long distance southward. He finds these five beds present in Wayne county southwest of Pulaski and extending to the Tennessee line. Clinton is west from Wayne along the Tennessee line and contains the most westerly fragments of the formation. Professor Loughridge's section gives the structure at a locality near the last western exposure:

	Feet
1. Conglomerate	30
2. Micaceous sandstone	42
3. *Coal bed* and fireclay	3 to 4
4. Shaly sandstone	140
5. Sandstone	60

an extreme thickness of about 275 feet and the rocks almost wholly sandstone. A thin coal bed was found resting on the lowest sandstone, so that here there remain the two persistent beds. The distinction between Sharon sandstones and sub-Sharon shales has disappeared. It is evident from the thickness of the mass that the shoreline must have been turned sharply westward as it passed beyond the area of Rockcastle county.†

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*Jos. Lesley: Fourth Report, pp. 480, 482.
G. M. Sullivan: Geology of Parts of Jackson and Rockcastle Counties, 1891, pp. 7, 15, 18.

†Jos. Lesley: Fourth Report, pp. 484, 485, 486, 488, 490.
R. H. Loughridge: Geology of Clinton County, 1890, pp. 24, 25.
C. J. Norwood: Tenth Annual Report of Inspector of Mines, 1894, p. 129.

Mr Campbell's studies in Pulaski, Rockcastle, and Jackson counties add to the knowledge of the Kentucky conditions and make easy the carrying of the section into Tennessee.

His Lee formation as defined in this area is evidently coextensive with the Rockcastle group of Professor Crandall, and is from 250 to perhaps 1,000 feet thick, thickening southward from Jackson into Pulaski. It consists of sandstones and sandy shales, including two conglomerates, the Corbin above and the Rockcastle below.

The Corbin, evidently the coarse upper plate of Lesley and equivalent in part to the upper bench of Mr Hodge, varies from conglomerate to coarse sandstone. It is unimportant in Jackson county, but thickens southward so as to be 200 feet in Pulaski, beyond which it continues with lessening thickness into Tennessee, where it becomes unimportant at 40 or 50 miles from the state line. The Rockcastle is at the bottom of the formation and varies in thickness from 0 to 150 feet. It occupies a pre-Pottsville valley, eroded deeply in Lower Carboniferous beds, and becomes prominent midway in Rockcastle county, whence northward it was followed to the final outcrop in Jackson county. This valley is perhaps 4 miles wide and the deposit, usually a coarse conglomerate, thins out on each side. This lower conglomerate in some part is doubtless equivalent to the lower conglomerate bench reported by Mr Sullivan.

The shales and sandstones overlying this Lee formation are termed Breathitt by Mr Campbell, and, so far as preserved in this area, are about 500 feet thick. Near the bottom is the important bed in Laurel county already referred to, which is apparently the Sharon or at very near its horizon. Mr Campbell refers to a coal bed underlying the Rockcastle conglomerate.*

Returning to the north, Lee county is south from Wolfe and east from Estill. Here Lesley finds the sub-Sharon deposits 296 feet thick at Proctor, while farther north the thickness is 195, decreasing northwest to about 100 feet in southern Powell, and finally in northern Menifee to 15 feet. There are five beds of coal in Lee county, at 5, 106, 122, 157, and 301 feet above the limestone, the highest being directly under the great sandstone cliff. The rocks vary much, but sandstones prevail in sone of the sections. Mr Lesley calls attention to the fact that the sandstone diminishes southwardly from 200 feet in Menifee county to 82 feet in Clay, and evidently thinks that the lower portion is replaced by shale, thus explaining the thickening of the sub-Sharon. But Professor Crandall notes that in Menifee, where the sandstone mass is thickest, the underlying shales attain their greatest thickness for the region. Mr

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*M. R. Campbell: U. S. Geol. Survey Folios. London, 1898; Richmond, 1898.

Hodge's section in Wolfe seems to make the matter clear, for from that county southward the sandstone is divided and new shales and new coals come into the section, which were unknown farther north. Mr Lesley's notes show also that even at a considerable distance eastward in the basin coarse materials prevail in the lower part of the section.*

The geology of eastern Pulaski is described by Professor Crandall in connection with that of Whitely, which is east from Pulaski and south from Laurel. The Sharon appears to be at very nearly the top of the section in eastern Pulaski. In eastern Pulaski the section reaches to but a little distance above the Sharon sandstone, which with the underlying beds is well shown in that county, as well as in western Whitely and along a branch of the Cumberland river in Laurel. Within this area the section assumes such importance that Professor Crandall terms it the Rockcastle group.

The upper plate of the Rockcastle group, the "Corbin lentil" of Mr Campbell, is from 100 to 200 feet thick, and the rocks between the coal beds are mostly coarse sandstones containing layers of quartz pebble conglomerate; but evidently the rock is less coarse in the bottom 150 feet. The lowest coal bed rests on the Lower Carboniferous limestone or is separated from it at most by only a few feet of shale. The other coal beds are approximately at 50–60, 90, 130, 240, and 310 feet above the limestone. The second, third, and sixth beds, known as the Bryvan, Main, and Barren Fork coals, are of great economic importance and mark horizons which show coal in nearly all of the sections for fully 100 miles northward. The other beds become locally valuable. The third bed is mined in Pulaski, Wayne, Whitely, and Laurel counties. It is the "Main" coal of the Cumberland and Rockcastle River region, and it was the important bed almost 50 years ago, when Mr Lesley made his study. The bed is usually double, with splint coal in one or the other bench and varies in thickness from 4 feet 4 inches to 4 feet 6 inches. The upper workable bed is usually in three benches with a total thickness of about 4 feet.†

The variations of the Rockcastle or lower portion of the Pottsville have been followed along the border from the Ohio river to the Tennessee line. On the Ohio river, where the most westerly exposure is considerably east from the line of Pike county, Ohio, the thickness is only a few feet; away from the river the Sharon sandstone reappears above the Sciotoville clay and thickens towards the south and southwest, while underneath these appears the shaly portion, which is prac-

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*Jos. Lesley: Fourth Report, pp. 475–477.
A. R. Crandall: Menifee County, p. 11.

†A. R. Crandall: Geology of Whitely and part of Pulaski, pp. 15, 16, 18, 20, 21.

tically unrepresented north from Scioto county in Ohio. We have seen the Sharon sandstone dividing into a coarse upper plate and less coarse lower plate, separated by coal-bearing shale, while farther south the upper plate undergoes further subdivision; but we have seen, following the mass southward, that instead of thinning, as at the north, toward the central line of the basin, it thickens in that direction, meanwhile growing coarser, so that near the Tennessee line it is a mass of sandstones separated by coal bearing shales in all not less than 450 feet thick and possibly much more.

We have seen also the coal horizon of the Jackson Shaft bed remaining comparatively unimportant until Menifee county was reached; but there the sub-Sharon shales expand and new coal horizons are shown, while farther south coal beds make their appearance in the Sharon sandstone itself, occupying places such as do the coal blossoms spoken of as occurring within northwestern Jackson county of Ohio. One is led to suggest that these may represent periods when isolated marshes along the western shore of the basin were filling with coal deposits; so that while those deposits were not continuous they may have been practically synchronous. In southern Kentucky favorable conditions lasted long enough for the accumulation of important beds, as was the case also in Tennessee.

Before studying the section above the Sharon sandstone in southeastern Kentucky, where it has been described so well by Professor Crandall, it is well to return to the north, in order to take up counties east from those already examined, that the section may be carried southward with certainty, for variations occur in the Upper Pottsville very similar to those already observed in the Lower. At the same time the variations of the Lower Pottsville will be considered as they are shown by sections obtained where that portion of the series has been brought up by faults or folds.

The Sharon, Quakertown, Mercer, and Tionesta coal beds have been followed across Greenup, Carter, and Elliott counties into Morgan, where the succession is clear.

The whole of the Pottsville is below drainage in Boyd county, lying between Greenup and the West Virginia line, as well as in much of Lawrence south from Boyd; but in western Lawrence the succession is very clear over to Blaine creek, for an anticline rising in central Lawrence and passing southwest into Johnson county brings up the Sharon sandstone in deep valleys of both counties.

The Ferriferous limestone is the lowest bed exposed on Dry fork of Little Sandy, in the southeast corner of Carter county; but thence the rocks rise toward the southeast, so that at the head of Dry fork that limestone is shown high up in the hills, with the Sharon coal bed at 280 feet below, while in a hill near by the Mercer is mined at 180 feet above the Sharon. Passing over to Big Blaine creek, which drains north Johnson and flows northwest across Lawrence to the Big Sandy river, one finds the Sharon sandstone along the forks in both counties. At the head of Blaine the Ferriferous limestone is 95 feet above the Mercer, which is 100 feet above the Quakertown. The intervals diminish in this direction, for in southern Carter that from the Ferriferous to the Sharon coal bed is 317 feet. In northwest Lawrence it is 280 feet, while on Irish creek of Blaine it is only 240 feet. The Mercer, Quakertown, and Sharon are all shown on Irish creek, where the intervals are 88 and 55 feet, and the Connoquenessing sandstones are well defined. In the southern part of the county the Mercer is 150 feet above the Sharon, which is separated from the Sharon sandstone by about 50 feet of shale.*

Passing into Morgan county, one finds in the northwest portion a section very similar to that of Elliott, but in the easterly and southern parts the section above the Sharon sandstone changes. In Greenup the Quakertown coal bed showed a tendency to divide, and at a number of localities a small bed was seen above Coal bed number 2, which Professor Crandall designated as "Number 2 A." This tendency is more marked in Carter and in the southern part of that county, where the interval between Mercer and Sharon has increased to 200 feet. The upper split of the Quakertown is at somewhat more than 75 feet below the Mercer. The section of western Carter prevails in Elliott and western Morgan, where the Quakertown is single; but in eastern Morgan the conditions observed in eastern Carter prevail, and the Quakertown splits are shown with increased interval. Not infrequently a thin coal bed appears underlying the Lower Connoquenessing sandstone, and several sections show a thin bed below the Sharon, resting directly on the Sharon sandstone.

In northwest Morgan the Sharon coal bed is from 40 to 60 feet above the Sharon sandstone, and the Quakertown at about 60 feet higher, while the little bed above the Sharon is 18 inches thick and 20 feet above the Sharon coal bed.

The Sharon coal bed is exposed in many places within western Morgan, where it appears to be thin, though occasionally reaching 3 feet. It is accompanied everywhere by the characteristic limestone bands and concretions, which are especially abundant in the underlying shales, though occasionally seen in those above; but the higher concretions in the overlying shales, reaching in some cases even to the Quakertown coal bed, are arenaceous limestone and in contrast with those in the underlying shales. The coal bed is below drainage in most of eastern Morgan and in most of Magoffin (south and east of Morgan), but the reversal of dip brings it to the surface and eventually far above drainage; so that the Sharon sandstone and the underlying shales are shown in western Johnson, the former being 100 feet thick and overlying a 20-inch coal bed. The Sharon sandstone shows its characteristic cross-bedding. The Sharon coal bed in Johnson and Floyd (southeast from Johnson) is from 50 to 60 feet above the sandstone, from 2 to 5 feet thick, and yields at most mines a coal of remarkable excellence. At one locality on Levisa fork of Big Sandy in eastern Johnson a thin cannel was seen at 50 feet below the Sharon bed. Mr Lyon found the same bed in southwest Johnson at about 70 feet below the Sharon and resting on sandy shales. He noted there the limestone concretions below the Sharon coal bed, which he finds characteristic of the horizon all the way to the Big Sandy river at the West Virginia line.

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*A. R. Crandall: Geology of Greenup, etcetera, pp. 51, 64, 65, secs. 47, 73, 76, 81.

The relation of the Sharon coal bed to the upper beds is shown in a section obtained by Professor Crandall in the southern part of Morgan, near the line of Wolfe county, which shows the Carter County conditions and prepares one for those seen in Wolfe and other counties at the south and east:

	Feet.	Inches
1. Sandstone, shale and shaly sandstone	30	0
2. Concealed	50	0
3. *Cannel, number 4* [*Tionesta*]	1 to 2	0
4. Sandstone and shale, imp. exp	42	0
5. *Coal bed number 3* [*Mercer*]		
5. Concealed	23	0
7. Sandstone	18	0
8. Concealed	20	0
9. Sandstone	20	0
10. Shale	5	0
11. *Coal bed 2A*, of which the *cannel* is 2 feet	4	7
12. Imperfectly exposed	50	0
13. *Coal bed number 2*, with *cannel* 2 feet	4	11
14. Sandstone and shale	68	0
15. *Coal bed number 1* [Sharon] in bed of creek		

The Ferriferous limestone, if present, should be in the hilltop, where fragments of iron ore are found, but apparently the limestone was not seen by Professor Crandall southward beyond the middle of the county, to which he had followed it from the Ohio river across Greenup, Carter, and Elliott counties. The Mercer coal bed is approximately 125 feet below it at this place. The interval between the Sharon and Mercer bed, 213 feet, is very nearly the same as in southern Carter, where the Quakertown beds are shown.

The shales overlying the Sharon sandstone, with their characteristic concretions, are shown along the branches of Licking river in southern Magoffin county, but Professor Crandall gives few detailed statements respecting the relations of the higher beds. The Sharon sandstone is exposed in Johnson county along Paint creek in the central portion, as well as along the forks of Blaine creek in the northern portion. The splits of the Quakertown persist in the sections of Johnson and Floyd counties, but the lower appears to be the more regular. In most of Carter, as well as Lawrence, the Quakertown is a bituminous coal, but in southern Carter it becomes cannel and continues as such into Morgan, and thence into several of the eastern and southern counties.

The Mercer coal bed in Johnson, Floyd, and Martin counties is broken by numerous partings and at times attains the thickness of 10 feet, including the partings. The Tionesta changes into splint toward the east, but the Quakertown remains cannel. The section on the border of Johnson, Floyd, and Martin counties, as compiled by Professor Crandall, is

	Feet.	Inches
1. Sandstone	30	0
2. Cannel		
3. Sandstone, etcetera	187	0
4. *Coal bed*	6	0
5. Clay, sandstone, and iron ore	46	0
6. *Coal bed*	1	6
7. Sandstone and shale	25	0
8. *Coal bed* with partings, *number 3*	10	0
9. Interval	88	0
10. *Cannel number 2A* (?)		
11. Shale and sandstone	50	0
12. *Coal bed number 2*	2	0
13. Interval	63	0
14. *Coal bed number 1*	3	8
15. Shale and sandstone	15	0

As this is a compiled section, the intervals are not exact for any one locality.

The Sharon is the Prestonburg bed of Floyd county, where a thin coal bed is present at 20 feet below it. This thin bed was seen at Paintsville at 35 feet, and the Sharon sandstone is above drainage at that place. The same bed is present elsewhere in Johnson county at varying distances below the Sharon bed.*

Mr Lyon ran a line of sections across Estill, Wolfe, Magoffin, Johnson, and Martin counties to the Tug fork of Big Sandy river at the West Virginia line. He followed the Sharon sandstone, with its underlying coal bed, into Wolfe county, where he found a coal bed, the Sharon, at 80 feet above it, the interval being filled with shale. On Stillwater creek, in Wolfe, he gives a section showing the Sharon at 61 feet below the Quakertown, and there he first saw the concretions in the shale, which he describes as occurring sometimes in almost continuous beds, while at others they are separated masses weighing tons. These he found thoroughly characteristic of the horizon from this locality to the Tug fork of Sandy river. The Quakertown coal bed, though only 2 feet thick, is triple. Eastward its partings thicken, so that at 5 miles away the thickness is somewhat more than 11 feet. A similar structure was observed in southwest Magoffin, but farther east the bed becomes shaly and the interval to the Sharon coal bed diminishes, becoming 49 feet in central and 16 feet in east Magoffin, where the upper bed is represented by 17 feet of bituminous shale. On the border between Magoffin and Johnson the interval is but " a few feet." Eastwardly they diverge, and the Quakertown, which had been merely a mass of bituminous shale, again carries coal. The higher beds are not shown in Mr Lyon's Magoffin sections, but they are present farther north in the region studied by Professor Crandall. The shales underlying the Sharon coal bed and carrying the calcareous concretions are so well marked on Licking river of Magoffin that Mr Lyon terms them the "Licking shales," and he states that they are reached in all the deeper valleys for 13 miles eastward, where, though sometimes showing more or less of sandstone, they retain all their characteristics. At one locality on the river he found a thin coal bed in these shales at 71 feet below the Sharon.

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*A. R. Crandall: Geology of Morgan, Johnson, Magoffin, and Floyd Counties, new series, vol. vi, pp. 323, 325, 326, 330, 334, secs. 2, 4, 6, 17, 18, 20.

In Johnson county the Quakertown is 61 feet above the Sharon and both are thin. The "Licking shales" increase in thickness and eventually become 150 feet, foreshadowing the still greater increase within the counties farther south along the Virginia line. For a few miles the Sharon coal bed is below drainage, though the Quakertown appears in all the sections; but it is reached again on Little Paint creek near the Levisa fork of Big Sandy river, where it is 34 feet below the lower split of the Quakertown and overlies 28 feet of shale carrying the characteristic calcareous bands and concretions. Higher beds are reached on Johns creek, east from Levisa fork, for there the section is

			Feet.	Inches
1. Sandstone and shales			34	0
2. *Coal bed*			6	6
Coal	2	4		
Clay	0	4		
Bituminous shale	1	10		
Coal	2	0		

	Feet.	Inches
3. Clay and sandy shale	19	0
4. *Coal bed*	0	8
5. Sandstone and shale, imperfect exposure	185	0
6. *Coal bed*		

Number 2, the Mercer coal bed, yields only bituminous coal. The interval to the Sharon, 204 feet, may be slightly too small, as the dip was ignored in the measurement. Lyon assigns certain coals in the neighborhood to 69 and 105 feet above the Sharon. The lower bed, approximately 140 feet below the Mercer, is reached in all the deeper valleys from Levisa fork to the state line, and the Mercer is frequently exposed.

Just east from the Levisa fork, Mr Lyon saw a quartz-pebble conglomerate at 540 feet above a coal which he took to be his "Adamsville" bed, the Sharon, but which better exposures eastward show to be the lowest bed, almost 100 feet below the Sharon. This conglomerate on Stonecoal branch of Rockcastle creek, in Martin county, is 100 feet thick and 244 feet above the Mercer coal bed, which is 10 feet 5 inches thick, with a 5 inch parting at 3 feet from the bottom. Near this locality coal beds were seen at 30 and 56 feet above the Mercer, which are present in Professor Crandall's section, and in addition a cannel underlies the conglomerate, according to both observers.

The section was followed to the Tug fork of Big Sandy river by Mr Lyon, the valleys being sometimes much deeper than enough to expose the Sharon coal bed, which Mr Lyon had followed for many miles under the names of the "Adamsville" or "A. J. Rice" coal. He finds this coal bed about 40 feet above the Tug fork at Warfield, with the underlying Licking shales carrying the characteristic concretions and bands so often referred to by him and Professor Crandall. On his return westward from the Tug fork, he followed the Licking shales to Paintsville in Johnson county, where the Sharon sandstone is above drainage.

Doctor White has given a section obtained at Warfield as follows:

	Feet.	Inches
1. Sandstone and shale	150	0
2. *Coal bed*	15	9
3. Concealed and sandstone	25	0
4. Silicious limestone	4	0
5. Shale and concealed	30	0
6. *Cannel*	2	0
7. Sandstone and concealed	30	0
8. Silicious limestone	1	0
9. Sandstone and concealed	20	0
10. *Coal bed*		
11. Concealed and sandstone	65	0

	Feet.	Inches
12. Silicious limestone	2	0
13. Massive sandstone	20	0
14. Shale and *coal*	0	7
15. Sandstone and shale	40	0
16. Massive sandstone	10	0
17. *Coal*	5	2
18. Concealed and sandstone	45	0
19. Silicious limestone	2	0
20. In boring	320	0

Number 17 is the Warfield coal bed. The interval to number 2 is 249 feet, about 40 feet more than at the west side of Martin county, showing that here is the increasing thickness of the section which becomes so marked in West Virginia. The Warfield coal bed, as will be seen, is the same with the Campbells Creek coal bed of the Kanawha valley, where one finds associated with it the limestone bands and lenticular masses such as characterize the horizon throughout a great part of Kentucky. A well record obtained in Mingo county of West Virginia, opposite Warfield, shows a coal bed, reported as 5 feet, at somewhat more than 100 feet below the Warfield coal bed, which is evidently the little bed observed in so many places by Lyon and Crandall. This record shows also a great change in the upper portion of the Rockcastle, for in 320 feet below this coal bed only two beds of sandstone appear, 18 and 20 feet thick. Below this for nearly 400 feet, sandstone predominates, but no trace of coal appears in the record.

Doctor White gives a section near Peach Orchard, in Lawrence county which is very similar to that at Warfield. The "Peach Orchard coal bed" is at 267 feet above the Warfield, the increase being very largely in the interval answering to numbers 3, 4, and 5 of the Warfield section. This Peach Orchard coal bed is regarded by Professor Crandall as the Coal 3 of the Kentucky section, and at Peach Orchard it is about 420 feet below the first Fossiliferous limestone. At Peach Orchard, as at Warfield, a sandstone overlies this coal bed which is very suggestive of that underlying Coal 4 in counties farther south.

The conglomerate at 250 feet above the Mercer coal bed is widespread through Johnson and Martin counties. It is somewhat more than 450 feet above the Sharon and immediately overlies a bed of cannel. Mr Lyon is inclined to identify it with the conglomerate which in so many places within Greenup and Carter counties overlies the Ferriferous limestone. The intervals have been increasing across the intervening counties, so that there is a probability that Mr Lyon's suggestion is a true one; but sections fail in Lawrence and much of Johnson, so the junction can not be made. The conglomerate appears to follow the Ferriferous along the western edge of the basin.[*]

The effort now is to trace the section through the more southerly counties of Kentucky, where the section begins to show extreme variation—a fact of some interest in view of the other fact that along the western border in this region the Rockcastle group begins to assume the proportions so notable farther south.

The Kentucky river is formed in Lee county by the union of three forks; the South fork, rising in western Bell county, flows northward through Clay and Owsley to Lee, which is south from Wolfe and east from Estill; the Middle fork, rising in Leslie, east from Clay, flows northward through Leslie, Perry, and Breathitt into Lee, while the North fork, rising in Letcher, flows through Letcher, Perry, and Breathitt into Lee and receives tributaries also from Wolfe. This region was studied by Mr Hodge.

Mr Hodge remarks that a noteworthy change in composition of the rocks takes place beyond a line extending across northwest Breathitt, southeast Owsley, and northern Clay. Up to this line from the northwest, the rocks above the Sharon sandstone are largely shale, but thence southeastwardly the shales are replaced in great part by sandstone and the measures thicken rapidly.

In central Wolfe county, at some distance south from Mr Lyon's line, Mr Hodge finds this succession, the identifications being by the writer:

		Feet
1.	*Coal bed* [Tionesta]	
2.	Interval	37
3.	*Coal bed* [Mercer]	
4.	Interval	50
5.	*Coal bed* [2A, Upper Quakertown]	
6.	Interval	62
7.	*Coal* and black shale [Quakertown]	
8.	Interval	35
9.	*Cannel* [1A]	
10.	Calcareous shales	27
11.	*Coal bed* [Sharon]	

Mr Hodge regards numbers 3, 7, and 11 as coal beds 3, 2, and 1 of the Kentucky series. Number 9 is the little coal bed seen at so many places between the Quakertown and the Sharon, and number 5 is evidently the same with the upper split of the Quakertown, which has been followed from southern Carter county. On Frozen creek, in northwest Breathitt, the Ferriferous limestone is shown at 200 to 220 feet above the Mercer coal bed (3), while an impure limestone, very thin, appears at 15 feet above the Mercer coal bed, and the Tionesta coal bed is shown at 32 feet higher. A coal bed is shown here at 66 feet above the Tionesta, not belonging to the Pottsville, but useful in carrying the section. This locality is 12 miles southeast from that of the Wolfe County section, and all of the intervals between the coal beds show a marked increase.

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[*] S. S. Lyon: Vol. iv (old series), pp. 534, 535, 536, 538, 542, 543, 589, 591, 593.

I. C. White: Bull. U. S. Geol. Survey, no. 65, p. 146. West Virginia Geol. Survey, vol. i, 1899, p. 276.

A. R. Crandall: Geology of Greenup, etc., sec. 87.

In this upper Kentucky River region Mr Hodge recognizes four persistent beds within the interval taken in this paper to represent the Upper Pottsville. These are numbered by him 1, 2, 3, and 4. The intervals vary as follows:

I. Between 4 and 3:
  50 feet in Wolfe county; 65 feet in northwest Breathitt; 140 feet in central Breathitt; 110 feet in northern Perry and northern Leslie; 205 feet at the border of Leslie and Harlan near Pine mountain.
II. Between 3 and 2:
  112 feet in central Wolfe; 132 feet in northwest Breathitt and northern Leslie.

The interval between 1 and 3 varies from 130 feet in Wolfe to 360 feet in Clay county.

Coal bed number 4 is the Hunnewell cannel of the more northern counties, the Tionesta of Pennsylvania and Ohio. Though occasionally cannel, as in the counties previously studied, it is more commonly splint coal. It is the most characteristic and persistent bed of the series, and it has been identified in most of the sections; so that it was used by Mr Hodge as the key-bed throughout. Overlying it at many places along the Middle and North forks is another bed, sometimes in actual contact, but at others as much as 30 feet above it. Still another probable split was seen, which, being distinctly separate at one locality, was numbered 4 B. These three beds must be considered as one bed on the North and Middle forks, though they become sufficiently distinct and widely separated in Clay county. This coal bed is the notable bed of Breathitt county, where it shows from 3 to 8 feet of cannel on the North fork; but in Perry it is much broken by partings, though usually of workable thickness. It is variable in Leslie county, but remains important even to the Pine Mountain region, in the southern part of the county.

The Mercer coal bed 3, which has been followed across Knott county and identified with the "Elkhorn coal bed" of the Pike County region, is important in Wolfe county, though divided by clay partings 2 to 13 inches thick. It varies abruptly in Breathitt, being sometimes a solid bed, but within a short distance becoming badly broken by partings. At one locality the bed is solid, yet within a mile it is represented by three beds, 6, 24, and 21 inches thick, respectively, and separated by 20 and 10 feet of shale. On another stream in the vicinity the three splits are shown in a vertical space of 50 feet. The same peculiarities are exhibited in Perry county. The bed is broken badly by partings in Leslie county near the Perry line, but within 5 miles southward it shows 3 to 4 feet of coal with partings in all of not more than 2 inches. These abrupt variations are characteristic of the bed in the northern counties. The coal in the several benches varies from bituminous to splint and even to cannel. Associated with this bed is number 3 A, which in Breathitt is 30 feet above the Mercer; but the interval increases southward, becoming 50 feet in northern Leslie and 85 feet on the Harlan border. It is unimportant on the north and middle forks, but appears to be fairly persistent.

The Quakertown is of little importance and usually gives only bituminous coal; but it is opened at many places in northwest Breathitt, northern Leslie, and northwest Perry. The coal bed, number 2 A of the northern counties, is insignificant. It was seen in Wolfe and Breathitt wherever its horizon is exposed, but everywhere it is very thin. The Sharon coal bed is shown in Wolfe and Breathitt, very variable, but yielding good coal where thick enough to be worked. A thin cannel, not more than 4 inches thick, is present sometimes at 30 feet, more or less, above it.

The interval from the Sharon coal bed to the Conglomerate is given by Mr. Hodge as about 10 feet—very much less than is given by other observers; but he states distinctly that he uses the term "Conglomerate" as a formation name and without reference to constitution, so that the difference is apparent, not real. Mr Moore gives the interval as 50 feet, evidently, like Lesley and Crandall, taking the massive sandstone as the top of the Conglomerate; but the interval shows remarkable variation, for Mr Hodge says that within short distances it may vary from practically nothing to 100 feet. It should be noted here that in Mr Hodge's sections along the North and Middle forks there is an "Upper Splint bed," his number 5; the interval to the Tionesta or Lower Splint being from 90 to 125 feet, the latter being at the south near Pine mountain, though even there it is at times only 90 feet. This bed, however, belongs to the Allegheny formation.

The line of change from shale to sandstone in the Upper Pottsville crosses northern Clay county, and with that change the intervals increase rapidly. No sections are available for Owsley county, lying between Lee and Clay, so that the sections in the last county appear to be in strange contrast with those of Wolfe and Breathitt. In northwest Clay the intervals are apparently not much greater than in northwest Breathitt, but as the beds are followed southeastwardly one soon finds the Sharon at 100 to 125 feet below the Quakertown and 250 feet below the Mercer. Coal bed 3A, which on the other forks of Kentucky river is simply a rider bed to the Mercer (3), becomes widely separated, until in southern Clay it is 125 feet above, while in the same neighborhood the Tionesta (4) is 425 feet above the Sharon (1). The thickening involves the higher measures also. In Wolfe county the ferriferous limestone is only 120 feet above the Tionesta, in Breathitt the interval is 130 to 150 feet, and in Clay it finally becomes 200 feet. In almost every section where the exposure is complete a coal bed, usually cannel, is shown at from 30 to 40 feet below the limestone. The splits from the Tionesta, 4A and 4B, become distinct beds in Clay, the interval to the latter being fully 100 feet in southern Clay.

Underneath the Tionesta, the Lower Splint, one finds a sandstone except in northwestern Clay and apparently in Wolfe. This thickens southward, becoming 80 and even 115 feet. In the northerly sections it is referred to as "mainly sandstone," but evidently it becomes more massive southward, so that on the border of Bell and Harlan counties it appears from the sections to be almost wholly sandstone. In sections within Clay, Bell, Perry, and Leslie counties, exposing the bottom of the sandstone, a thin coal is shown at never more than 5 or 10 feet below it.*

Professor Crandall made a preliminary study of Pike, Letcher, Harlan, and Bell counties, the eastern tier along the line of Virginia and West Virginia. Pine mountain is the state line to almost the southwest edge of Letcher, whence to the Tennessee line it is the northwesterly boundary of Harlan and Bell counties. The great fault of this mountain brings up the Pottsville with extraordinarily increased thickness, there being in the Pike County region, belonging to the lower portion, about 2,000 feet of rock, coarse ferruginous and more or less conglomerate sandstones alternating with shales so as to form five or six benches. Cross-bedding prevails throughout, and the pebbles are from mere grains to three-fourths of an inch in diameter. Thin coal beds exist in the shales, but they are unimportant.

The shales overlying the lower Pottsville have continued to increase. Crandall found them 50 feet in western Greenup and 150 feet in Lawrence. Lesley found them increasing eastward from a few feet on the western outcrop to upward of 150 feet in Martin county, these being his "Licking shales." Across Floyd and Knott counties the increase is even more marked; so that in Pike and Letcher they reach an apparent maximum of 450 feet. The calcareous bands and concretions, first becoming abundant in Lawrence and characterizing the shales along the western border even to the Tennessee line, are even more prominent here and are distributed through about 300 feet of the section, while the number of coal beds belonging to their general horizon has increased to at least four. The increased number of coal beds throughout the section renders detailed comparison with more western localities impossible, as the work has not been connected fully, but the upper limit of the Pottsville appears to have been traced carefully. For more than 50 miles the tracing was checked above by the Ferriferous limestone, and beyond that the peculiar characteristics of the upper coal beds made identification easy.

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*A. M. Hodge: Preliminary Reports on Southeastern Kentucky Coal Field, 1887, pp. 59, 64, 67, 72, 73, 74, 75, 78, 80, 82, 98, sections 81, 84, 85, 86, 87, 88, 89, 90, 100, 102.

The information at present available is not sufficient to justify a positive identification of any one bed as the Sharon, as it is represented apparently by several beds. The equivalent of the Quakertown is equally uncertain. Below the Mercer, which is identified positively, there are three beds, each occasionally of workable thickness, at 40, 140, and 165 feet, all of them above the great mass of shale and sandstone, which also contains several thin coal beds. The middle bed is thought by Professor Crandall to be the probable equivalent of his number 1 (Sharon), but this suggestion is merely tentative in the absence of detailed sections.

Kentucky coal bed number 3, taken as the Mercer in this paper, is readily identifiable with the Elkhorn coal bed of Pike county, which Professor Crandall thinks is the equivalent of the "Imboden coal bed" of southwestern Virginia. It is of great economic importance in the adjoining portions of Knott, Floyd, and Pike counties, as well as in Letcher. As usual, it is subject to extreme variations, often abrupt; but it is frequently of workable thickness under large areas and yields a superior coking coal. At 100 to 130 feet above it is number 4, the Tionesta, the Lower Splint bed, which is so characteristic throughout Breathitt, Leslie, and Perry and is so well known farther north as the Upper Cannel or the Hunnewell Cannel of Greenup and other counties. Underlying this coal bed is a great sandstone, to which reference has been made in the description of other counties, with at most localities a thin coal bed under the sandstone. At somewhat more than 100 feet above this bed is the Upper Splint, as in the counties at the west, with a cannel at about 150 feet higher, both belonging to the Allegheny formation, while at somewhat more than 600 feet above the Elkhorn (Mercer) coal bed is a fossiliferous limestone, which appears to be persistent. These three deposits of the Allegheny formation will prove serviceable in the effort to make correlations along the eastern outcrop in southwestern Virginia.*

The area beyond Pine mountain will be considered in connection with southwestern Virginia.

Returning now to the southwestern area, the line may be taken in Laurel and Whitely counties, answering to northwestern Breathitt, where the intervals are not so great as in the eastern counties and the "Licking shales" are not so greatly developed. The intervals which had become so extreme in Clay persist southward into Knox, as appears from a section given by Professor Norwood;† but they decrease rapidly westward, so that in Laurel, west from Knox, one finds the intervals not very different from those in Wolfe and Breathitt. Nothing is available for this area except a mere reconnaissance, which suffices merely for recognition of the general horizons.

Professor Crandall places the first workable coal bed at 50 to 75 feet above the top of his Rockcastle group, the great upper conglomerate of that group being the "Corbin lentil" of Mr Campbell. This Laurel coal bed he identified with number 1, which is sufficiently consistent with the tracing along the western outcrop. It is shown in Laurel county practically to the Knox border in the deep valley of a fork of Cumberland river, so that a series of sections should be possible in Knox county by which to settle all questions relating to the equivalency of the higher beds.

The third workable bed is known as the "Jellico" and is at about 200 feet above the Laurel, while at about midway between the two is a cannel which attains much importance locally. These intervals suggest that the three beds may be at the Sharon, Quakertown, and Mercer horizons. At 75 to 100 feet above the Jellico is a splint coal bed, the interval being filled mostly by sandstone. This higher bed, the Cadell, is described as semi-cannel, free-burning. It underlies another bed, 72 feet higher. This section suggests that the higher beds are the two splints, numbers 4 and 5.

The calcareous concretions and bands, which in the central and northern counties belong to the horizon of coal beds 1 and 2, extend here through more than 200 feet vertically and are found even in the shale underlying the Jellico, as in Pike county, where they are found occasionally in shales underlying the Elkhorn.*

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*A. R. Crandall: Preliminary Reports on Southeastern Kentucky Coal Field, 1887, pp. 14, 15, 18, 28.

†C. J. Norwood: Report of Inspector of Mines for 1893, p. 112.

TENNESSEE

Passing over into Tennessee, along the western border, one has the following succession:

Corbin sandstone,
Shales,
Rockcastle sandstone,
Shales,

resting on the Lower Carboniferous. According to Mr Campbell, the Rockcastle rests on the Lower Carboniferous at a little way north from the Tennessee line, though eastward in Whitely county the underlying shales become important and contain at least two important coal beds, the "Main Cumberland" and the "Bryvan," as well as a third at the bottom, which is rarely important. Above the Corbin at 50 to 70 feet is the "Pittsburg or Laurel coal bed," which appears to be the equivalent of the Sharon of Pennsylvania. The Corbin and the Rockcastle in Tennessee are often conglomerate. Mr Campbell's work was carried into Tennessee, so that direct linking of Kentucky studies with those of the workers in Tennessee becomes comparatively simple. His notes concern the western border of the Cumberland plateau in Fentress and Cumberland counties, where the Rockcastle is practically the highest bed of the section, except near the Kentucky line, where the Corbin is seen at 100 feet higher. The Rockcastle, separated from the Lower Carboniferous by from 150 to 300 feet of shale, loses it coarseness southward so as to become merely a sandstone at somewhat more than 40 miles south from the Kentucky line. Meanwhile a sandstone makes its appearance in the lower part of the underlying shales, increasing in coarseness and importance, so that where the Rockcastle ceases to be a marked feature of the topography this lower conglomerate, the Bonair of Campbell, forms massive cliffs at approximately 125 feet below the Rockcastle along the western border. At first it rests almost directly on the Lower Carboniferous, but followed southward, the interval increases until, in White county at Bonair, it is 110 feet and contains mostly shales with a coal bed at the bottom. Mr Campbell notes the presence of some thin coal beds between the Rockcastle and the Bonair within the area studied by him, but hesitates to make identifications with the beds observed farther south. The Bonair or lowest conglomerate ceases to be an important member of the section north from Monterey in Cumberland county, where a 3-foot coal bed was seen directly under it and almost in contact with the Pennington shale.*

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*A. R. Crandall: Geology of Whitely County and part of Pulaski, pp. 24, 25, 28–37, 39, 42.

Professor Safford's detailed sections illustrate the formation as it occurs in Fentress, Overton, and Putnam counties, the last two being west and southwest from Fentress, which extends to the Kentucky border. In southwest Fentress he finds both the Rockcastle and the Bonair, the succession being as follows:

		Feet.
1.	Conglomerate [Rockcastle]	40
2.	Shale	51
3.	Sandstone	6
4.	Shale	21
5.	Sandstone	46
6.	Shale and sandy shale	50
7.	Conglomerate [Bonair]	90
8.	*Coal bed*	0 to 3
9.	Fireclay, shale and sandstone	4
10.	Shale and iron ore	25 to 30

He suggests that coal should occur in the shales, numbers 2, 4, and 6, but no exposure was found. The shales number 10 may belong to the Shenango (Pennington of Campbell). The lower conglomerate, "Main" of Safford, "Bonair" of Campbell, forms the cap-rock in much of the region, while the Upper conglomerate, Rockcastle of Campbell, is the cap-rock of much the greater part of Safford's northern division of the Cumberland Plateau in Tennessee.

In southeast Overton adjoining southwest Fentress, Professor Safford found on the east fork of Obey river a coal bed at 110 feet below the Rockcastle and 54 feet above the Bonair, underlying the sandstone, number 5 of the section just given. This, which is 4 feet thick and yields excellent coal, is evidently the "Sewanee coal bed," so important farther south. The interval between the conglomerates here is 168 feet; it is 174 at a few miles east within Fentress. Farther north in Overton county, say 6 or 8 miles, a coal bed was seen at 180 feet below the Rockcastle, and at a mile farther east coal beds were seen at 95 and 165 feet below the Rockcastle, 1 foot and 3 feet 6 inches thick; and Safford says respecting the lower bed "that this is followed not far below by the Main conglomerate." At both of the northern localities the great sandstone between the conglomerates shown in the southern Fentress section is wanting, so that it may not extend farther north than southern Fentress. No details are available for northern Overton, so that the northward extent of the Bonair can not be determined. The presence of this lower conglomerate in Overton county is interesting, for it is absent from western Fentress except in the extreme southwest. Professor Safford's section at 4 miles west from Jamestown, near the Overton border, shows a very abrupt change to the conditions described by Mr Campbell in Fentress county, for the succession is

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* M. R. Campbell: U. S. Geol. Survey, Standing Stone folio, 1899.

1. Conglomerate, very heavy	Not measured
2. Shale and sandstones	97 to 102
3. *Coal bed*	3 to 4
4. Concealed	4
5. Sandstone	20
6. Concealed to the Mountain Limestone	30

The coal bed is evidently the Sewanee, shown in southeast Overton at 54 feet above the Main (Bonair) conglomerate. The whole thickness below the Rockcastle is but 158 feet. At 6 miles east from Jamestown, in Fentress county, coal beds are shown at 40 and 61 feet below the Rockcastle, the lower bed being 4 to 5 feet thick.

Putnam county is south from Overton. Apparently there is little here above the Main (Bonair) conglomerate, which in the central part of the county is thin, with an unusual thickness of shale above and below it, so that Professor Safford thinks it largely replaced by shale. A thin coal bed, 2 feet, was seen above the conglomerate, and an important though variable bed is directly under it. The underlying shales vary greatly, for on Sinking Cane they are almost 100 feet, whereas on Calfkiller creek, barely a mile away, they are but 61 feet.*

Evidently Professor Safford regarded the conglomerate of western Fentress as his Main conglomerate, but in view of the studies made in Fentress and Cumberland by Mr Campbell and in eastern Fentress by Mr Keith, the deposit must be taken as the Rockcastle of Campbell. The Bonair, according to Mr Campbell, extends but little beyond Monterey in Cumberland county, for it changes northwest from that point and the shales underlying the Rockcastle are very much thicker there than elsewhere. Though present in Overton, as shown by Safford's sections, it is clearly wanting in much of Fentress. Its boundary is a line from southwest Fentress northeastward, and passing just west of Rugby, where oil borings prove its presence. Mr Campbell says that it is unknown farther north on the south fork of Cumberland river, so that it must be confined to southwestern Fentress.

Southward from Fentress, Putnam, and western Cumberland, along the western border, one has the work of Professor Safford and Mr Hayes to the Alabama line. It may be well to adopt, for convenience of description, Professor Safford's division of the area, considering first the region

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J. M. Safford: Geology of Tennessee, 1869, pp. 393, 396, 397, 398.

west from the Crab Orchard anticlinal followed by the Sequatchie valley, and afterward Walden ridge, forming the narrow strip east from that valley and extending to the eastern escarpment of the Cumberland plateau.

Mr Hayes divides the Upper Carboniferous rocks of southern Tennessee into Lookout sandstone, below, and Walden sandstone, above. The Lookout extends upward to the top of the Main (Bonair) conglomerate. "The Walden" is described as consisting of

1. A coarse, heavy sandstone, usually conglomerate.
2. Sandy shales.
3. Variable thickness of coarse, white, or yellow sandstone, containing pebbles; forms surface of much of Bledsoe and Cumberland counties.
4. Several hundred feet of shales, some approaching fireclay, others passing through micaceous, sandy shales into thin bedded sandstone; most important as containing chief coal bed of the region. This mass decreases westward and disappears near the western escarpment.

The full thickness of the beds as thus described is seen only near the Sequatchie valley, where it is 650 feet. As the Walden rests on the Bonair conglomerate, one must recognize in number 3 the Rockcastle, and in number 1 the Corbin of Campbell.

White county is south from Putnam. In the northeastern part of the county, on Calfkiller creek, Professor Safford found

	Feet.	Inches.	Feet
1. Conglomerate [Main, Bonair]	Not measured.		
2. Shales	80	0	
3. Sandstone [Etna, Cliff]	13	0	
4. *Coal* and fireclay	1	0	to 2
5. Shale	12	0	
6. *Coal bed*	3	6	
7. Clay and concealed	32	0	

to the Lower Carboniferous. The important coal bed is at 106 feet below the Bonair. Here appears for the first time in the sections the sandstone, number 3, which farther south becomes "Safford's Cliff sandstone" or "Lower Etna conglomerate." At 4 miles north from Bonair the interval to the sandstone appears to be not more than 23 feet, and a coal bed 2 to 3 feet thick rests on the sandstone. At little more than 2 miles from Bonair, four coal beds are shown below the Bonair in about 100 feet of measures, and the Bonair is 90 feet thick. At Bonair, Professor Safford found the Bonair 90 feet thick, with 102 feet of measures below containing several thin seams of coal. Mr Campbell gives the thickness below as 110 feet, with an important coal bed very near the bottom. On Clifty creek, near "Caney Fork gulf," Professor Safford obtained the following interesting section:

	Feet.	Inches
1. Sandstone and conglomerate [Corbin?]	65	
2. Shale		0 to 12
3. *Coal bed*		2 to 6
4. Fireclay and shale	62	
5. Sandstone [Rockcastle]	40	
6. Shale	20	
7. Fireclay	1	
8. Shale and sandstone	25	
9. Shale	52	
10. *Coal bed* [Sewanee]	3	
11. Shale	25	
12. Main Conglomerate [Bonair]	60	
13. Shale with *coal*	15	

to the Lower Carboniferous. There is a decided shortening of the section throughout, so that the sandstone, number 1, may well be taken as the Corbin; number 8 represents the important sandstone so frequently found between the Rockcastle and Bonair, which at this western locality has degenerated. The sub-Bonair beds have almost disappeared; a similar condition was observed by Mr Hayes on the border of Bledsoe and Cumberland counties, several miles southeast, where the Conglomerate rests directly on the Lower Carboniferous. But this preexisting ridge of Lower Carboniferous recognized by Mr Hayes must be very narrow, for Professor Safford, though giving the Clifty Creek section as characteristic of the formation in much of Van Buren south from White, says that the "Lower Coal Measures," those below the Bonair conglomerate, thicken eastwardly, and he shows that they thicken westwardly also, for they are 100 feet in White county westwardly from the section just given. Mr Hayes also shows that they thicken in each direction; for while on the border of Cumberland and Bledsoe east from White and Van Buren he finds Bonair and Lower Carboniferous in contact, he finds the lower beds in Van Buren. In Warren, west from Van Buren, on the extreme western outlying patch of the plateau, he finds at 6 and 7 miles southeast from McMinnville these sections:

	I		II
	Feet.	Inches.	Feet
1. Cross-bedded sandstone [Bonair]	50		25
2. Shales	30		25
3. *Coal bed*		8 to 10	3 to 4
4. Cross-bedded sandstone [Etna, Cliff]	50		
5. Shales	20		100
6. *Coal bed*	1	6 to 2 feet	
7. Shales	Thin		

to the Bangor limestone.

Mr Hayes gives two sections farther east in this division—the first in northern Cumberland county at probably 12 miles east from the Calfkiller Creek locality, in White, and the second in central Bledsoe near the Sequatchie valley. They are important as illustrating the eastward thickening of the measures, and must be given in full that the change from the western to the eastern conditions may be understood. The Cumberland section is

	Feet.	Inches
1. Coarse sandstone [Rockcastle]	60	
2. Interval	100	
3. *Coal bed* [Sewanee]	1	11
4. Shale and sandstone	80	
5. Conglomerate and sandstone [Bonair]	55	
6. *Coal bed*		
7. Interval	240	

to the Bangor limestone, showing a great increase in the sub-Bonair measures and a moderate increase in the beds above. The Pikeville section in Bledsoe, about 25 miles farther south, is

	Feet.	Inches
1. Sandstone with some shale [Corbin?]	75	
2. *Coal bed*		
3. Shales and sandstone	300	
4. Coarse sandstone [Rockcastle].	35	
5. *Coal bed*		2 to 4
6. Sandstone and shales not fully exposed	140	
7. *Coal bed* [Sewanee]	3	
8. Shales and sandstones	90	
9. Conglomerate and sandstone [Bonair]	60	
10. *Coal bed*	1	6
11. Not fully exposed	340	
12. *Coal bed*	1	6 to 2
13. Thin shale to Bangor limestone		

It is altogether probable that the highest sandstone of this section is at the Corbin horizon or very near it, as the shales overlying the Rockcastle show a very great thickening in sections northeastward from the Pikeville region, to which reference will be made when studying the eastern escarpment. It is probable that here one finds the full presentation of the Rockcastle formation of Crandall, the Lee formation of Campbell's Kentucky folios. The Sewanee coal bed appears to be absent from a considerable portion of western Cumberland and a portion of White, but it is important in Bledsoe and most of Cumberland.

Farther southward the region under consideration includes Grundy and Franklin counties along the western border, with so much of Marion as lies west from Sequatchie valley, the last two extending to the Alabama line. The Lookout sandstone of Hayes, having the Main (Bonair) conglomerate as its upper bed, forms the plateau, with detached areas of Walden sandstone in the several counties. The Lookout, inclusive of the Bonair, decreases from 510 feet at Sequatchie valley to 120 feet at the western outcrop. Mr Hayes finds the Walden 550 feet in eastern Grundy, 475 in eastern Marion, and only 300 feet in southern Grundy. These figures refer not to the full thickness, but only to that of the portion remaining. Professor Safford gives a detailed section near Tracy City, in southern Grundy and northern Marion, as follows:

	Feet.	Inches.		Feet.	Inches
1. Conglomerate [Rockcastle]	50	0			
2. *Coal bed*					
3. Shale	23	0			
4. *Coal bed*	0	6			
5. Shale	26	0			
6. Sandstone	86	0			
7. Sandy shale	45	0			
8. *Coal bed* [main Sewanee]	3	0	to	7	
9. Shale	33	0			
10. *Coal bed*	1	0			
11. Shale and sandstone	17	0			
12. Conglomerate [Bonair]	70	0			
13. *Coal bed*	1	0	to	0	6
14. Shale	10	0			
15. Cliff sandstone [Etna]	65	0			
16. *Coal bed* [Etna]	1	6	to	0	6
17. Shale	30	0			
18. Hard sandstone	78	0			
19. *Coal bed*	1	0	to	3	
20. Hard sandstone	20	0			
21. Shale to mountain limestone	20	0			

The average thickness of the Upper Measures is given as 240 feet, and that of the Lower Measures as 228 feet, not including the conglomerates. The sandstone of White county below the Rockcastle has doubled in thickness, and the Sewanee coal bed is at a greater distance above the Bonair, though less than in central Bledsoe, where it is possible some of the interval may be accounted for by uncertainty respecting the top of the Bonair. The average interval in these southern counties is not far from 50 feet. The Cliff sandstone, extending northward apparently no farther than White county, increases in importance southwardly and is a marked feature in much of Alabama; but the interval between it and the Bonair is variable; sometimes the two deposits are in contact, while at others they are separated by 150 feet. In northern Grundy they seem to be in contact, for there Professor Safford's section is

		Feet.	Inches
1.	Conglomerate	130	
2.	*Coal* and shale	25	
3.	Sandy shale	50	
4.	*Coal bed*	0	6

resting on the limestone. Evidently the Bonair and Cliff are one here, the thickness given being only 5 feet less than the combined thicknesses at Tracy City. A thin coal bed underlying the conglomerate mass becomes 3 feet thick within a short distance; it is the "Etna" of Safford, the "Cliff bed" of the Alabama reports. The sandy shale of number 3 is the hard sandstone, number 18, of the Tracy City section, which there also overlies a coal bed. The bottom members of the Tracy section have disappeared. Farther north there is a greater decrease below the Cliff, the whole thickness is 54 feet, while at the northern border of the county it is less than 20 feet and the coal beds are only one foot apart. Evidently a condition like that observed in White and on the border of Bledsoe and Cumberland must exist in southern or southeastern Van Buren.

The Sewanee coal bed is mined at many places around the petty areas of the Walden in the southern counties. At the Sewanee mines in southern Grundy it is from 2 feet 6 inches to 7 feet and yields a somewhat crushed coal; at most localities a small bed, the Jackson of Safford, appears between it and the Bonair, but it is rarely thick enough to be mined.

In Franklin county, west from Marion, the Lookout sandstone is present for two or three miles beyond the Marion line. Professor Safford gives two sections, one of which is within a half mile of the Alabama line, near Anderson, as follows:

		Feet.	Inches
1.	[Bonair]	Not measured	
2.	Shale with thin *coal bed*	40	
3.	Cliff sandstone, estimated	120	
4.	Coal bed [Etna], average	3	
5.	Fireclay, shale, and sandstone	31	
6.	Sandstone and sandy shale	55	
7.	Shale	1	to 6
8.	*Coal bed*	2	6 to 3
9.	Shale	Not measured	

The shale at the bottom is 38 feet thick in the other section at a short distance farther north. The thickness of the Cliff sandstone may be excessive, for in the other section it measured but 74 feet.

The Sewanee coal bed is mined at several localities along the westerly side of the Sequatchie valley. Mr Hayes obtained sections in northeast Marion 2 miles apart, which illustrate the structure, as follows:

	I		II	
	Feet.	Inches.	Feet.	Inches
1 Conglomerate and coarse sandstone	20		60	
2. Shale	50		25	
3. *Coal bed*	1		1	2
4. Shale and sandstone	150		125	
5. *Coal bed*	0	6	0	6
6. Shales and sandstone	200		200	
7. *Sewanee coal bed*	4 to 5	9	4	
8. Shale and sandstone	45		40	
9. *Coal bed* [*Jackson*]	1			
10. Shale	5		10	
11. Conglomerate and shale [Bonair]	70		65	
12. "*Cliff vein*" *coal bed*	0	8	0	8
13. Cross-bedded sandstone [Cliff, Etna]	100		95	
14. *Coal bed* [Etna]				
15. Sandstone and shale	210		200	
16. *Coal bed*	0	9	0	9
17. Shales	60		50	

to the Bangor limestone. In the second section a coarse sandstone, apparently almost 100 feet thick, begins at about 50 feet above the Sewanee coal bed; it is not so well shown in the other. This is the sandstone which it 86 feet at Tracy. The sandstone at 60 feet higher and about 70 feet thick is evidently the Rockcastle, the interval to the Bonair being somewhat less than 270 feet, only 30 feet more than at Tracy City, 14 miles toward the west. The "Cliff vein" of the section is not the bed known by that name in Alabama, which underlies the Cliff sandstone and is the Etna of Safford. The relations of the coarse sandstone at the top of the section are not clear; it is too near the Rockcastle to be the Corbin—at least such appears to be the condition by comparisons of the sections already given.

Farther south along the west side of the Sequatchie valley are two sections of the lower beds by Safford

	I		II	
	Feet.	Inches.	Feet.	Inches
1. Conglomerate [Bonair]				
2. Shale and *coal*	Thin		0 to 1	6
3. Sandstone and shale	60		68	
4. Cliff sandstone	90		105	
5. *Coal bed* [Etna]	2		Thin	
6. Shale	10		8	
7. Shale	0		6	
8. *Coal bed*	4		1 to 4	

	I	II
	Feet	Feet
9. Fireclay and shale	67	110
10. *Coal bed*		
11. Sandstone	12	

giving in the second, which reaches to the bottom, a thickness of about 350 feet—an increase of about 125 feet in comparison with Tracy City and of about 150 feet in comparison with Franklin county, but nearly 100 feet less than is shown by Mr Hayes's sections 8 or 10 miles farther northeast.*

Crossing now to the eastern portion of the Cumberland plateau, separated from the main area by the Sequatchie valley and known as "Waldens ridge," one finds little difficulty in following the section northward from the Alabama line, though the thickening of the measures causes perplexity at times. This area embraces portions of Marion, Hamilton, Sequatchie, Bledsoe, Rhea, and Cumberland; but the name is applied to the east portion of the plateau as far as the northern boundary of Tennessee, so that there may be included also portions of Roane, Morgan, Anderson, and Campbell counties. In its southern portion, Waldens ridge is sometimes spoken of as "Raccoon mountain," the name which it bears in Alabama.

The Etna mines are in southeast Marion at about 2 miles north from the Alabama line, about 10 miles west from Chattanooga, and somewhat farther east from the western side of the Sequatchie valley. The section extends from the Lower Carboniferous up to the great sandstone midway between the Bonair and the Rockcastle. It was studied nearly 50 years ago by Professor Safford and almost 30 years later by Professor Colton. The two sections are presented together, number 1 being that by Professor Safford:

	I		II		
	Feet.	Inches.	Feet.	Inches	
1. Sandstone	75		73		
2. Shale	48		32		Shaly sandstone
3. *Walker's coal bed*	4		4		
4. Shale with coal bed	30 to 40		46		
5. *Coal bed, Slate vein*	5 to 6		6		
6. Shale	44		44		
7. *Kelly coal bed*	2 to 3		2 to 5		
8. Fireclay	1 to 2		1	6	
9. Main conglomerate	75		82		Upper conglomerate
10. *Coal bed*	Thin		0	3	

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*J. M. Safford: Geology of Tennessee, pp. 355, 369, 370, 372, 373, 374, 376, 379, 392, 393.

C. W. Hayes: U. S. Geol. Survey folios, Kingston, 1892; Chattanooga, 1892; Pikeville, 1895; McMinnville.

	I		II		
	Feet.	Inches.	Feet.	Inches	
11. Shale	30 to 40		45		Yellow sandy shale
12. *Coal bed*	0	10	Thin		
13. Sandy shale	100 to 130		45		Gray shales
			2 to 1		Coal bed
			45		Gray sandy shales
14. Lower Etna conglomerate, Cliff rock	70 to 100		96		
15. Shale	0 to 12		0		
16. *Coal bed, Main Etna,* or *Cliff vein*	3		2 to 5		
17. Fireclay and shale	6 to 23		22		
18. *Coal bed*	1 to 6		1		*Dade* or *Eureka coal bed*
19. Sandstone	80 to 120		95		Gray shale
20. Shale	0 to 5				
21. *Coal bed*	3 to 6		0	6	
22. Fireclay, shales, and sandstone	35 to 47		20		Black shale
23. *Coal bed*	3 to 6		3		
24. Fireclay, shales, and sandstones	80 to 150		74		Shale
			2		*Coal bed*
			102		Fireclay shales and sandstone

Professor Safford's section is not purely local, but it was intended to be representative of conditions within the space south from the Tennessee river. The close agreement of these sections, made at so great an interval of time and under very different conditions, is a welcome testimony to the skill and accuracy of Professor Safford, whose survey of Tennessee was made very largely at his own cost and without the many conveniences now regarded as essential by geologists.

The " Kelly coal " of the section is clearly the " Jackson coal bed," as Professor Safford recognizes, and he is inclined to regard the " Walker " and " Slate " beds as equivalent to the " Sewanee " of the western localities. Professor Colton identifies with the Sewanee his bed at 45 feet above the Cliff sandstone, but this identification, which has been accepted by Mr McCalley in the Alabama reports, is not consistent with the type section, where that coal bed is above the Bonair and at a varying interval below the sandstone which is at the top of both Etna sections. The thickness below the Bonair in Professor Colton's section is about 550 feet, coinciding with the average of the measurements given by Professor Safford.*

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* J. M. Safford : Geol. of Tennessee, p. 383.

H. E. Colton : Cited by H. McCalley, Geol. Survey of Alabama, Coal Measures of Plateau Region, 1891, p. 18.

Mr Hayes gives a section obtained near the Etna mines, which differs somewhat from those by Safford and Colton. It is

		Feet.	Inches
1.	Sandstone	75	
2.	Shale and sandstone	120	
3.	*Coal bed, Etna*	4	
4.	Shales	50	
5.	Trace of *coal*		
6.	Shales and sandstones	120	
7.	*Sewanee (?) coal bed*	1	6
8.	Shale and some sandstone	70	
9.	*Soddy (?) coal bed*	1	2
10.	Sandstone and shale	25	
11.	Conglomerate and massive sandstone	80	
12.	*Castle Rock coal bed*	3	
13.	Shale	30	
14.	Trace of *coal*		
15.	Shale	65	
16.	*Dade coal bed*	3	
17.	Shale	20	
18.	Mostly concealed	250	

to the Lower Carboniferous.

The top of the Lookout here, number 11, is the Cliff sandstone of Safford and Colton, which will be referred to hereafter as the Etna conglomerate, for along the eastern escarpment in Tennessee, as well as in much of Alabama, it is as important as the Bonair or Main conglomerate of Safford. The "Castle Rock" coal bed of this section is the Main Etna coal bed of Safford, the Cliff vein of this region and Alabama, the Castle Rock of Georgia. The bottom of the sandstone at the top of the section is almost 400 feet above the Etna (Cliff) conglomerate, and it is evidently the same with that of the other sections, in which it is at about 360 feet. The Etna coal bed of this section is evidently the Slate bed of Safford, the number 5 of Colton, which should be at somewhat less than 50 feet above the Bonair. Where Mr Hayes's section was obtained, the Bonair seems to have been replaced by shale, as no trace of the conglomerate appears in his section. The coal bed, hesitatingly identified with the Sewanee, may be the coal bed, 30 to 45 feet below the Bonair in the other sections, and the "Soddy" (?) coal bed is evidently that seen by Professor Colton at 45 feet above the Etna (Cliff) conglomerate. The Walker coal belongs in the interval number 2. The thickness of measures below the Etna conglomerate is somewhat greater than that given in the other sections.*

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*C. W. Hayes: U. S. Geol. Suryey folios, Chattanooga, 1892.

Before proceeding further with the Waldens Ridge area in Tennessee, it is necessary to review summarily the conditions in Alabama.

ALABAMA

The Cumberland plateau of Mr McCalley lies north from the Tennessee river and west from Sequatchie or Browns valley, thus including parts of Jackson, Madison, and Marshall counties.

Mr McCalley takes as the basis of comparison the section obtained by Professor Colton at Etna and that by Professor Safford in southeastern Franklin county, both within 2 or 3 miles of the Alabama line. The Bonair conglomerate (Upper or Main of Safford) is the highest rock in most of this area and forms the "Second bluff," the "First" or "Lower bluff" being that of the Etna (Cliff) sandstone, commonly called the "Millstone grit." As in Tennessee, these conglomerates vary from coarse quartzose sandstones to pebbly rock and are separated by an interval of 25 to 150 or more feet. The Lower Measures, underlying the Etna sandstone, are rarely more than 50 feet thick in the plateau, though in other portions of the state they appear to be thicker than in any portion of Tennessee.

The outliers in Madison county are farther west than those of Franklin in Tennessee. The Etna, the highest bed in most of Madison, is a massive sandstone without pebbles and not more than 75 feet thick; at the western exposures it rests directly on the Etna coal bed and the interval to the Lower Carboniferous limestone varies from 2 to 20 feet. In northwest Jackson, the Etna sandstone, 50 to 80 feet thick, overlies the Etna (Cliff) coal bed, which is 2 to 10 feet above the limestone, but on Poor House mountain the interval is 60 feet; on Keel mountain, farther east, both Bonair and Etna are shown with the Etna coal bed represented by several layers distributed through 20 feet of section. At Limerock, in the southern part of the county, the Lower Measures are much thicker; thus

	Feet
1. Cliff rock [Etna]	70
2. *Cliff coal seam* [*Etna*]	4
3. Fireclay	4
4. Shale and sandstone	200
5. *Coal* and fireclay	1 to 3
6. Heavy bedded sandstone	25
7. Concretionary sandstone	12

giving 247 feet below the Etna sandstone. No details are available for Marshall county.*

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* H. McCalley: Geol. Survey of Alabama, Coal Measures of Plateau region, 1891, pp. 25, 30, 31, 32, 38, 59.

Waldens ridge as it crosses northwest Georgia becomes Raccoon mountain, and the name is retained in Alabama. Sequatchie becomes Browns valley and continues practically to the south line of Blount county, about 50 miles from the Tennessee line. On the east, Raccoon mountain is cut off by Wills valley, continuous with the Great valley of Tennessee and separating Raccoon from Lookout mountain, which begins just north from the Tennessee line.

In Dade county, the most northwesterly in Georgia, Mr McCalley's section at the Dade mines is

	Feet.	Inches.		Feet.	Inches
1. Cliff sandstone [Etna]	75	0			
2. *Cliff coal* [*Etna*]	2	0	to		6
3. Shale	50	0			
4. *Dade coal*	17	0	to	1	
5. Shale and clay	45	0			
6. *Red Ash coal bed*	3	0	to		6
7. Fireclay and sandstone	81	0			
8. *Coal bed*	1	2	to		10
9. Shale to the Limestone	40	0			

about 225 feet between the Etna sandstone and the Lower Carboniferous limestone. Farther west, near the Alabama line, at the Castle Rock mines, the place of the "Red ash" coal bed is concealed, but the other beds are exposed. The interval from the lowest coal to the limestone appears to be 250 feet, and the thickness of the Lower measures is about 500 feet.

The Etna sandstone forms the main bluff on the west side of Raccoon mountain in Jackson county of Alabama. It is 60 feet thick at 4 miles from the Georgia line, but increases to 100 feet on Long Island creek, 4 miles farther southward. The immediately underlying Etna coal bed persists in the sections and rarely exceeds 2 feet. A coal bed at about 50 feet above the Etna sandstone is shown in many sections, varying from 6 inches to 3 feet. It is evidently the same with the Sewanee of Colton's section and seems to be very near the place of the Cashie coal bed in Gibson's Blount Mountain section. That name will be used in the descriptions. Mr McCalley's section at 18 miles from the Georgia line is

	Feet.	Inches.		Feet.	Inches
1. Conglomerate [Bonair]					
2. Sandstone debris	30	0			
3. *Coal* and sandstone	0	4			
4. Clayey shale	2	0			
5. *Coal bed*	1	0	to		8
6. Ill exposed	20	0			
7. *Coal* in shaly sandstone	1	6			
8. *Coal bed* [*Cashie*]	0	10	to		4
9. Interval	40	0	to	30	
10. Cliff rock, Millstone grit [Etna]	80	0	to	100	

with the Etna coal bed, thin and worthless, underlying the sandstone. Farther south 20 feet of the Bonair remain in place at only 30 feet above the Etna. The latter rock decreases in thickness locally, for at a little more than 20 miles from the state line it is but 30 feet, with the "Cashie" coal bed at 22 feet above it. Respecting the rock at this place, Mr McCalley says: "For several feet up in this Lower Conglomerate, from its base, there run streaks of hard cubical coal, filling cracks in the conglomerate; the thicker of these coal seams sometimes divide up into many coal streaks." In the extreme southern part of Jackson county, near the Marshall line, both conglomerates are shown, each 50 to 60 feet thick, separated by an interval of only 10 feet, including the Cashie coal bed.

Mr McCalley gives a number of sections in Marshall county south from Jackson. The interval between the conglomerates increases, so that at the Blount county line it is 70 feet, with the Cashie coal bed persistent. The Etna coal bed is triple, and the interval from the top of the Etna sandstone to the Lower Carboniferous limestone has decreased to 140 feet—little more than one-fourth of the thickness at the Georgia line.

On the easterly side of Raccoon mountain the Bonair is 75 to 80 feet at Browns gap, 2 miles from the Georgia line, where it is massive and almost wholly pebbles. The interval to the Lower Carboniferous is approximately 300 feet, showing a rapid decrease within a few miles southeast. In this region the Etna is a mass of pebbles, but farther south it is less pebbly, and in places is merely a cross-bedded sandstone. The interval between the conglomerates increases southward until it becomes 90 feet in northern Etowah county, south from Marshall. The Cashie and Etna coal beds persist in the sections, but they are usually thin, rarely reaching workable thickness.*

Raccoon mountain is divided in Blount and Etowah counties by Murphrees valley, originating near the north line of Etowah and passing southwest through Blount until it unites with the Coosa or Birmingham valley, which topographically is a continuation of Wills valley. The portion lying between these valleys is known as Blounts mountain, while that west from Murphrees to Browns (Sequatchie) valley retains the name of Raccoon mountain. The conditions in Blount mountain, as described by Mr Gibson, contrast strangely with those in the area farther north. It is evident that the thicknesses assigned by him to some of the beds are merely estimates and in excess, but it is equally evident that there is an abrupt thickening of the whole column.

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* H. McCalley: Op. cit., pp. 44, 45, 47, 48, 49, 50, 52, 57, 75, 81, 82, 107.

The Lower Measures, including the Etna conglomerate, nowhere exceed 300 feet along the east side of Raccoon in De Kalb county, and the interval between Bonair and Etna is only 90 feet. In Marshall, on the west side of Raccoon, the interval between the conglomerates is 70 feet, and the Lower Measures at most 140 feet; but within 10 miles southwestwardly Mr Gibson estimates the Lower Measures at 800 feet and the interval between the conglomerates at 500 feet. As will be seen, these estimates approximate the thicknesses in Waldens ridge of Tennessee.

The Etna or first conglomerate of Blount mountain is 50 to 100 feet thick, and varies from a mass of rounded pebbles to a coarse grained sandstone. The second conglomerate, unhesitatingly identified by Mr Gibson with McCalley's upper conglomerate, the Bonair, is easily distinguished from the Etna, as its pebbles are less firmly cemented, and where pebbles are absent the rock is light gray. Its thickness increases southwestwardly, being 100 feet on Lime creek in Etowah county, while midway in Blount mountain it is estimated at between 400 and 500 feet—estimated because no measurements can be obtained. A third conglomerate, at approximately 1,000 feet above the Bonair, is composed of "good sized, but not well rounded pebbles, firmly cemented together with carbonate of iron." A fourth conglomerate occurs very near the top of the formation, about 1,250 feet above the third. Its upper portion is "light colored, loosely cemented, and weathers badly, and is hence seldom seen on the surface," but its place is shown by the abundance of large rounded pebbles. The lower part is harder and better preserved. The total thickness is not more than 55 feet, and the underlying rocks for 100 feet are "quartzites."

The interval between the Etna and Bonair is 110 feet in Etowah county at a little distance from Lime creek. Two miles southwest, as calculated from the dip, it is somewhat less than 250 feet. At 5 miles farther it was thought to exceed 500 feet; thence southwestwardly it decreases, becoming 100 feet or even less in the southwestern part of the area. It is unfortunate that no detailed measurements of the higher portions of the section are given for the northeastern part of the area. Mr Gibson's map shows that measures to a considerable distance above the third conglomerate are present at not more than 5 miles southwest from Lime creek. It has been seen that the interval between Bonair and Etna increases southwest from 90 feet in Etowah to possibly 500 feet on headwaters of Blackburns fork; that the Bonair increases in the same distance from 110 to 400 feet or more, while the Lower Measures increase from 300 to 800 feet. As all portions from the Bonair downward show this extreme increase, one is led to surmise that the upper portion increases in like manner. The temptation to suggest that the third and fourth conglomerates are equivalent to the Rockcastle and Corbin is very great, the more so because midway between the Bonair and the third there is a great and persistent sandstone holding a relative place very like that of the persistent sandstone above the Sewanee coal bed in the Tennessee sections. But in the absence of beds above the Bonair conglomerate almost everywhere south from the Etna mines, in Tennessee, to Blount county stratigraphy is helpless, and the final determination must be made by means of palæobotany. Happily the material is within easy reach, for plant-bearing beds are present at several horizons up to within 200 feet of the fourth conglomerate. More than twenty-five years ago Leo Lesquereux, after studying the plant remains, referred the formation to the Pottsville.* Mr Gibson's section shows twenty-six coal beds above the Etna conglomerate, most of which attain workable thickness in some portion of the area. Three beds are persistent between the Bonair and Etna, the middle one being the Cashie. The coal beds in the Lower Measures are insignificant.†

The Raccoon Mountain area may be regarded as extending only to the southern line of Blount county, where Sequatchie-Browns valley terminates and Raccoon becomes continuous with the Great Warrior coal field, covering a large area west from Browns valley and tapering southward to Tuscaloosa. At the west and south the Coal Measures pass under the cretaceous beds. Messrs Gibson and McCalley have studied the formation in Blount county. The work of the latter was merely reconnaissance, but he traced the Bonair on both sides of Raccoon and found the Etna coal bed at a few localities, nowhere more than 1 foot thick. Whether or not more than one coal bed are present between the conglomerates was not ascertained.‡

Mr Gibson's section of Berry mountain, a high fragment remaining in the southern part of Blount county, contrasts strangely with the section on Blount mountain on Blackburns fork, about 6 miles toward the southeast. The measures below the Etna are but 30 to 40 feet thick. The Bonair and Etna conglomerates are each 50 to 60 feet and are separated by 25 to 30 feet of flaggy sandstone with clay. Seven hundred feet of measures remain above the Bonair, with coal beds at 150–200, 250–300, 375–425, 455–500, 475–520, and 495–535 feet above that conglomerate. One can not determine the equivalents of these beds in the general section of Blount mountain. Plant-bearing shales are present near the top of the section.§

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* E. A. Smith in letter to writer.

† A. M. Gibson: Geol. Survey of Alabama, Coal Measures of Blount Mountain, 1893, pp. 17, 18, 21 22, 23, 32, 33, 36, 38, 42, 47, 49.

‡ H. McCalley: Op. cit., pp. 132–134.

§ A. M. Gibson: Coal Measures of Plateau Region, pp. 192, 193.

Before taking up consideration of the Warrior coal field, one must record the features of isolated fields lying toward the east in position comparable with that of the Southern and Middle anthracite fields of Pennsylvania. These are Lookout mountain, occupying a synclinal extending from the Tennessee line across northwest Georgia into Alabama and terminating near Gadsden; the Cahaba field, beginning 20 miles southwest from Gadsden and extending about 40 miles in almost direct continuation of the Lookout strike, and finally the Coosa coal field, southeast from the Cahaba field and about 37 miles long.

The Lookout Mountain coal field, beginning in Hamilton county of Tennessee, passes southwest across Dade and Walker of Georgia, De Kalb, Cherokee, and Etowah of Alabama, and terminates near the Coosa river. As the coal beds are of comparatively little importance, detailed information is scanty.

Professor Safford's section at the north end shows

	Feet
1. Upper conglomerate, very heavy, pebbly, estimated.	250
2. Trace of *coal*	
3. Fireclay and sandy shale	1 to 39
4. Conglomerate	37
5. Shale	23
6. Trace of *coal*	
7. Sandy shale and some sandstone	305 to 320

Professor Spencer's section at the same locality differs very little. His measurement gives 225 feet as the thickness of number 1, the bottom 50 feet being a massive conglomerate and the upper portion chiefly cross-bedded sandstone. This mass evidently includes both Bonair and Etna, and the underlying coal bed, mined at a few miles farther south, is recognized by Spencer as equivalent to the Etna (Castle Rock) of Raccoon mountain.

The basin deepens southward, so that within 6 miles from the Tennessee line Professor Spencer obtained a long section, thus:

	Feet.	Inches.		Feet.	Inches
1. Shales and concealed	274	0			
2. *Coal* and shale	14	0			
3. Shale and concealed	43	0			
4. Sandstone	35	0			
5. *Coal bed*	3	6	to	4	6
6. Sandstone	35				
7. Shales, red, black, blue, variegated, with thin limestone	32	0			
8. *Coal bed*	1	10			
9. Red and blue shales	105	0			

	Feet.	Inches.	Feet
10. *Coal bed*	0	2	
11. Shales and sandstones, variable	150	0	
12. *Coal bed*	1	8	
13. Massive sandstone, some shale	27	0	
14. *Coal bed*	0	2	to 9
15. Upper Conglomerate and sandstone	150	0	
16. Shales	120	0	
17. Lower Conglomerate and sandstone	40	0	
18. Shales and concealed, estimated	250	0	

The feature of especial interest is the presence of red, blue, and variegated shales so far down in the section. Number 6 is certainly not higher than the Rockcastle sandstone; yet below it is a mass of shales suggesting the Conemaugh conditions. The interval from the top of the Upper to the bottom of the Lower conglomerate is practically the same as in the other section. The Etna and "Dade" coal beds are mined within 2 miles of this locality. The beds numbers 2 and 5 were seen by Mr Hayes, who gives about 60 feet as the interval. The lower bed is of importance. Number 13 is at the horizon of the Sewanee, while the two thick beds are at the horizon of important beds in southern Kentucky.*

Passing over into Alabama, one finds Mr McCalley's general section of the measures,

	Feet.	Inches.	Feet.	Inches
1. Sandstone	75	0	to 0	
2. *Coal bed*	2	0	to 0	4
3. Shales	10	0	to 4	
4. *Coal bed*	0	10	to 0	0
5. Shale	30	0	to 25	
6. *Coal bed*	1	8	to 0	3
7. Upper Conglomerate [Bonair]	60	0	to 50	
8. *Coal bed*	1	0	to 0	
9. Shales	9	0	to 0	
10. *Coal bed* [Cashie]	3	6	to 2	
11. Shales and sandstone	40	0	to 35	
12. Lower Conglomerate [Etna]	100	0	to 25	
13. *Coal bed* [Etna, Cliff, Castle Rock]	2	0	to 0	
14. Sandstone and shale	50	0	to 40	
15. *Coal bed, Dade, Eureka*	2	8	to 2	8
16. Fireclay with fossil stems	20	0	to 3	
17. *Coal bed*	1	6	to 0	6
18. Sandstone and shale, estimated	250			

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* J. M. Safford: Geol. of Tennessee, p. 385.
J. W. Spencer: Geol. Survey of Georgia, the Paleozoic Group, 1893, pp. 135, 139, 254-257.
C. W. Hayes: U. S. Geol. Survey folio, Ringgold, 1894.

The variable bed, represented by numbers 2, 3, and 4, is at the Sewanee horizon, and number 6 is at the Jackson horizon of southern Tennessee; both beds seem to be persistent to the southern end of the field, and the Sewanee is mined to some extent for use in Gadsden. The Cashie coal bed is important near Fort Payne of De Kalb county, but in Cherokee and Etowah it rarely exceeds 1 foot. It often underlies the Bonair directly and sometimes it is distributed irregularly through the bottom layers of that deposit. In like manner the Etna coal bed often occurs as strings or pockets in the Etna sandstone and it is rarely of any value. The Dade coal varies greatly, but sometimes, as at the Eureka mines in De Kalb, is thick enough to be mined, but all of the beds tend to become thinner toward the southern end of the field.

The Bonair is very coarse near the Georgia line; it becomes less coarse southward, and within 8 or 10 miles is merely a coarse sandstone, about 60 feet thick. The Etna is not conglomerate; usually is a more or less cross-bedded sandstone, much of it massive. In De Kalb it is about 60 feet; in Cherokee, from 75 to 100 feet, and in Etowah about 75 feet. The interval between Bonair and Etna varies from 15 to 60 feet, and the total thickness from the top of the former to the bottom of the latter is somewhat more than 200 feet, approximately the thickness assigned by Professor Spencer to his Upper Conglomerate at the north end of the field.*

The Cahaba coal field, embracing portions of Saint Clair, Jefferson, Shelby, and Tuscaloosa counties, was studied by Mr Squire wholly with a view to determine economic values, so that the details of beds, aside from coals, are scanty. The diagrammatic sections on the map reveal the presence of very little shale, the rocks being sandstone, gritty slate, and conglomerate. The topmost 500 feet are almost wholly conglomerate. The aggregate thickness assigned by Mr Squire is 5,525 feet. The conditions observed in Blount mountain are clearly only a transition from those in Raccoon to those in Cahaba, as well as to those in Coosa. The Millstone Grit group is about 1,700 feet thick, and consists mostly of pebbly rocks and gritty slates. There are evidently three great beds of conglomerate separated by gritty slates, with several thin coal beds, only two of which appear to be persistent. One of these underlies what may be taken as the Etna conglomerate, and is at about 250 feet above the Lower Carboniferous limestone, the interval being filled with rocks less coarse than the overlying conglomerate. On top of the massive Etna, about 300 feet thick, one finds gritty slates extending to the second great conglomerate, which with the slates is about 650 feet. The upper division is about 500 feet thick—conglomerate, sandstone, and gritty slates. The middle conglomerate is identified by Mr Gibson with his second conglomerate of Blount mountain, the Bonair. If this identification be correct, the important coal bed above is at the Sewanee horizon. The immense mass of conglomerate at the top is thought by Mr Gibson to be the same with his fourth conglomerate of Blount mountain, but this conclusion awaits confirmation.*

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* H. McCalley: Coal Measures of Plateau Region, pp. 84, 87, 88, 89, 91, 94–97, 105.

The Coosa coal field, embracing parts of Saint Clair and Shelby counties, is only 3 or 4 miles east from the last, being separated from it by the Cahaba valley. Mr Gibson gives 5,750 feet as the thickness of Coal Measures in the deepest portion of the basin. He has traced his First and Second conglomerates (Etna and Bonair) through a great part of the field, but they are greatly increased in thickness and are separated by about 200 feet of shale, the total being nowhere less than 1,200 feet, while in one part it may be 1,500. He recognizes his Fourth conglomerate in 500 feet of conglomerate and quartzitic rocks near the top of the section, evidently the top conglomerate of the Cahaba field. Mr Gibson especially emphasizes the thickening of the coarser beds; the First (Etna) conglomerate, only 80 to 100 feet in Blount mountain, is 400 to 500 feet here, and the Fourth conglomerate shows an almost equal increase. The coal beds, almost twenty in number, are persistent, and half of them are workable, while one of them attains a thickness of 13 feet of solid coal.†

The thickness assigned to the sandstones in the Cahaba and Coosa fields may be excessive, but numerous opportunities for direct measurement were found, and such measurements prove sufficiently that Mr Gibson is correct in asserting so firmly that the coarser deposits thicken rapidly toward the east.

The western part of the Warrior coal field is properly the southern termination of the great Indiana-Illinois coal field, from which, however, it is separated by an interval of more than 200 miles. The general conditions were the same throughout this southern part of both basins, as appears from the close resemblance of the sections obtained in the several counties. The work in this field was performed by Mr McCalley.

The elevated ridge, forming the eastern edge of the field along Browns valley and the northern edge across Marshall, Morgan, Lawrence, and Franklin almost to the Mississippi border, is known as Sand mountain.

The continuation of the Raccoon area lies east from the Warrior river, in Jefferson and Tuscaloosa counties, and passes under the Cretaceous near the latitude of Tuscaloosa, a few miles north from the similar termination of the Cahaba field in Bibb county. The section in Jefferson and Tuscaloosa is very long, showing somewhat more than 3,000 feet of Coal Measures, fully 2,800 feet being above the Bonair sandstone. The Etna sandstone, at about 40 feet above the Lower Carboniferous, is light colored, massive, coarse, but without pebbles. and from 40 to 75 feet thick, with the thin Etna coal bed immediately below it, and the Dade, or perhaps a lower bench of the Etna, at from 3 to 10 feet lower. The Bonair, 30 to 50 feet thick, is somewhat pebbly, is about 50 feet above the Etna, and rests on the Cashie coal bed. The Jackson and Sewanee horizons are represented by coals at 5 and 41 feet above the Bonair.

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* J. Squire: Geol. Survey of Alabama, Cahaba Coal Field, 1890, pp. 4, 5, 14. Diagrams of sections on the map.

† A. M. Gibson: Geol. Survey of Alabama, the Coosa Coal Field, 1895, pp. 26, 55, 79, 81, 125.

The detrital deposits above the Sewanee horizon show extreme variability, intervals being given as 50 to 300 feet, 25 to 125 feet, 60 to 225 feet in the generalized section. Fossiliferous limestones, associated with sandstones also containing marine fossils, are at about 1,000, 1,300, 1,950, and 3,000 feet above the base of the formation, but these limestones are local in distribution. Two persistent conglomerates, both thin, are shown, one at about 1,500 feet above the base and the other toward the top of the series. Several non-persistent conglomerates appear in the upper 600 feet of the section, but they are all thin and mere lentils. One may recognize the third conglomerate of Blount mountain, and in the coarser beds at the top of the section there appears to be the representative of the conglomerates of the Coosa and Cahaba fields. Mr McCalley reports 50 coal beds above the Bonair, but for the most part they are very thin, though several of them become economically important under large areas. It is difficult, in the absence of detailed sections, to make proper comparisons with the Coosa and Cahaba fields, but the thickness of the coal beds in the Coosa field and the diminished number there seems to suggest that the many beds reported by McCalley in the Warrior may represent separated benches of thicker beds at the east.

Variegated shales make their appearance at about 1,000 feet above the base, and thence upward are of frequent occurrence. In Walker county, west from Jefferson, a red sandstone, 25 feet thick, is shown at a little way below the Third conglomerate. The rocks generally are soft, and the sandstones tend to be shaly; but the section in this county, as well as in Fayette and Lamar westward to the Mississippi border, does not reach downward to the Bonair.

Northward from this tier of counties the section becomes shorter, so that in Cullman there remain only about 1,000 feet above the Bonair. Here, as in Jefferson, no determination can be made of relations above the Sewanee coal bed, which underlies about 500 feet of shales and sandstones. Both Bonair and Etna are here, massive and more or less pebbly; but they are thin, about 30 feet, and averaging 40 feet apart. The Cashie and Etna coal beds are insignificant, and the interval to the Lower Carboniferous is from 30 to 40 feet. In Winston, west from Cullman, the detrital beds are coarser, and sandstone seems to prevail above the Bonair. In counties along the northern outcrop the section remaining extends to but a short distance above the Bonair. Both sandstones are present to the last exposure at the west, within two or three miles of the Mississippi line. They retain a thickness of approximately 60 feet, but toward the west become less massive and are divided by beds of shale. The interval below the Etna, 30 to 40 feet in Marshall, increases westwardly to 60 feet in Morgan and almost 100 feet in Franklin.*

TENNESSEE

Returning now to Tennessee, at the Daisy mines, about 20 miles north from Chattanooga, on the eastern escarpment, Mr Hayes obtained a section as follows:

	Feet.	Inches
1. Sandstone	50	0
2. Shale	10	0
3. *Coal bed* [Sewanee]	3	6
4. Shale and sandstone	25	0
5. Sandstone [Bonair]	65	0
6. Shales and concealed	85	0
7. Sandstone	20	0
8. Concealed	60	0
9. *Soddy coal bed*		
10. Clay and shale	5	0
11. Conglomerate and massive sandstone [Etna]	80	0
12. *Coal bed* [Etna]	3	0
13. Shales, some sandstone	100	0
14. *Coal bed*	1	6
15. Shales, some sandstone	155	0
16. Trace of *coal*		
17. Shales and sandstone	115	0
18. Concealed	70	0
19. Shales and sandstone	30	0

The succession is sufficiently clear. The coal bed number 3, at 260 feet above the Etna conglomerate, which here also is the top of the Lookout, is the Slate vein of the Safford Etna section, the Sewanee coal bed of the Tracy City section. The Bonair is present at the Daisy mines as a massive sandstone at 25 feet below the Sewanee. The Soddy coal bed rests almost directly on the Etna (Cliff) conglomerate. The Etna (Cliff-Castle Rock) coal bed is 3 feet thick and is mined. The Dade coal bed of Mr Hayes' Etna section is here at 100 feet below the Etna coal, approximately the same distance as in that section; but here it is not of workable thickness.

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* H. McCalley: Geol. Survey of Alabama, Warrior coal field, 1886. For Jefferson and Tuscaloosa, pp. 273, 416, 417; Walker, Fayette, and Lamar, pp. 99, 110, 131-134; Cullman, pp. 89, 90, 93: Marion and Winston, pp. 30, 31, 64, 65.

The Plateau region. For Blount, pp. 208-215; for Marshall, Morgan, and Franklin, pp. 59, 64, 65, 69, 70, 71, 73.

Mr Hayes' section at Rathbun, a few miles northeast from the Daisy mines, is important; it is as follows, the identifications in brackets being by the writer:

	Feet.	Inches
1. Sandstone	65	0
2. *Coal bed* [*Walker*]	2	0
3. Sandstone and shale	65	0
4. *Coal bed* [*Slate, Sewanee*]	3	2
5. Shale and sandstone	50	0
6. Sandstone [Bonair]	75	0
7. Shale	20	0
8. *Coal bed*	3	0
9. Sandstone and shale	50	0
10. *Coal bed*	5	0
11. Shale	30	0
12. *Coal bed*	1	3
13. Shale	40	0
14. *Soddy coal bed*	4	6
15. Interval	5	0
16. Conglomerate and massive sandstone [Etna]	70	0
17. Shale	10	0
18. *Coal bed* [Etna]	1	6
19. Shale	30	0
20. *Coal bed* [*Dade* of Colton]	1	0
21. Shale, a little sandstone	185	0
22. *Coal bed*	1	6
23. Shale	55	0
24. *Coal bed*	2	4
25. Shale	15	0
26. Sandstone	50	0
27. Shale	10	0
28. *Coal bed*	1	8
29. Shale and sandstone	25	0
30. *Coal bed*	1	3
31. Mostly shale	85	0

The interval between Bonair and Etna is 158 feet; at Daisy, it is 170, and at Etna, 140. The Sewanee is 283 feet above the Etna conglomerate, and underlying the sandstone is the Walker, which may be, as Safford suggested, merely a split from the Sewanee. Four coal beds are present in the interval between the conglomerates and three of them are of workable thickness. The Soddy, workable here and at the Daisy, does not appear in the other sections. The Bonair is evidently only a sandstone, but the Etna (Cliff) is conglomerate. Below the latter the measures are 475 feet, a notable thickening in the northeasterly direction, and this thickening is at the bottom of the column. The lowest coal bed at Etna is about 200 feet below the Etna conglomerate or at the place of number 22 of the Rathbun section; but in the latter are three lower beds, the lowest at nearly 400 feet.

At Graysville, in southern Rhea county, about 12 miles northeast from Rathbun, another section was obtained by Mr Hayes, as follows:

	Feet.	Inches.	Feet
1. Sandstones, shales, and concealed	550	0	
2. *Bony coal*	5	0	
3. Shales and sandstone	90	0	
4. *Nelson coal bed* [Sewanee]	3	0	
5. Shales	35	0	
6. Conglomerate and massive sandstone [Bonair]	115	0	
7. Shale	40	0	
8. *Bony coal*	0	8	
9. Shale and sandstone	40	0	
10. Sandstone	60	0	
11. Shale	50	0	
12. *Coal bed*	0	0	to 3
13. Shale and sandstone	110	0	

The lower rocks concealed or not measured.

Number 6 is the top of the Lookout; it here includes some of the underlying shale, replaced by sandstone, as well as some of the overlying sandstone. The " Nelson " bed is at the horizon of the Sewanee and is 190 feet above number 10, which is in the place of the number 10 at Rathbun, while number 10 is at 150 feet above number 14, which holds the place of the Etna coal bed in the Rathbun section. At Dayton, also in Rhea county and about 5 miles northeast from Graysville, Mr Hayes obtained a very important section, which is as follows, the identifications in brackets being, as in other sections, by the writer:

	Feet.	Inches
1. Sandstone [Corbin]	75	0
2. Shale	20	0
3. Sandstone	15	0
4. Shale	25	0
5. *Richland coal bed*	4	0
6. Shale and sandstone	35	0
7. Sandstone	65	0
8. Shale	20	0
9. Sandstone and shale	75	0

	Feet.	Inches.	Feet
10. Shale	75	0	
11. Sandstone [Rockcastle]	70	0	
12. Shales	50	0	
13. *Coal bed*	1	0	
14. Shale	70	0	
15. Sandstone	25	0	
16. *Coal bed*	0	4	
17. Shale and some sandstone	75	0	
18. *Nelson coal bed* [Sewanee]	5	0	
19. Shale and some sandstone	55	0	
20. Conglomerate and massive sandstone [Bonair]	70	0	
21. *Coal bed*	0	2	
22. Shale and sandstone	90	0	
23. *Coal bed*	0	10	
24. Shale and sandstone	165	0	
25. *Coal bed*	3	0	to 4

Here one reaches the higher measures again. The succession above the Nelson (Sewanee) coal bed appears to be clear; the sandstone, number 15, is that so persistent between the Bonair and Rockcastle; number 11 is the Rockcastle, about 280 feet above the Bonair, and number 1, at about 330 feet above the Rockcastle, is in place of the Corbin, that being very nearly the interval at Pikeville, almost due west from Dayton. If these identifications be correct, the Richland coal of Hayes is at the horizon of the Barren Fork coal bed in Pulaski county of Kentucky.

No section or note is available for the region northeast from Dayton until Rockwood, 30 miles distant, in Roane county, is reached. There Mr Hayes' section is

	Feet.	Inches
1. Sandstone	150	0
2. Shale	25	0
3. *Richland coal bed*		
4. Shale and sandstone	85	0
5. Massive sandstone	140	0
6. Shale	25	0
7. Trace of *coal*		
8. Shale	15	0
9. Sandstone	310	0
10. *Rockwood coal bed* [Sewanee]		
11. Shale	50	0
12. Conglomerate and sandstone [Bonair]	70	0
13. *Coal bed*		
14. Sandstone and concealed	300	0
15. *Coal bed*	0	2
16. Shale and concealed	175	0

to the Lower Carboniferous limestone, giving for the Lookout formation a total of about 550 feet, inclusive of some part of the Pennington shales of Campbell and Keith (Shenango). Surmise is dangerous where the gaps are so wide, but the sections seem to suggest that the Bonair and Etna conglomerates come together between Rathbun and Graysville, as they do in the region west from Sequatchie valley, not far from the latitude of Graysville, and that the combined mass is thinner. This is the more probable, since northward from Rathbun the escarpment is cut back and all members of the formation thin very rapidly toward the west for several miles from the escarpment. Mr Hayes says that the Lookout diminishes from 510 feet on the escarpment to 260 feet in the Crab Orchard range, only 4 or 5 miles toward the west.*

Professor Safford's section in the gap through Crab Orchard, about 8 miles west from Rockwood, reinforces the suggestion. This locality is midway between Rockwood and Crossville. He finds the "Conglomerate" 100 to 150 feet thick, with the Sewanee ("Haley's") coal bed at 30 to 40 feet above it, while below the conglomerate there are but 228 feet of measures.†

But, however the conditions may be at Rockwood and southwestward, the Bonair and Etna (Cliff) conglomerates are distinct at Harriman, 12 miles northeastward from Rockwood, where the escarpment extends farther toward the east. Mr Hayes gives a short section at Harriman showing an interval of 155 feet between the "Rockwood-Harriman" coal bed and the little bed below the Bonair. About thirty years ago Professor Bradley compiled a general section north from Harriman, which is of great importance, as it was measured carefully.‡ It is

	Feet.	Inches.		Feet
1. Shales	140	0		
2. *Coal bed*	1	6		
3. Shale and sandstone	179	0		
4. *Coal bed*				
5. Shale and sandstone	90	0		
6. *Coal bed*	1	0	to	3
7. Shale and sandstone	110	0		
8. *Coal bed*, reported to be	1	0		
9. Interval	50	0		
10. *Coal bed*, said to be	1	6		
11. Interval	193	0		
12. Heavy bedded sandstone [Corbin]	153	0		
13. Mostly shale	320	0		
14. Irregularly bedded sandstone [Rockcastle]	50	0	to	70
15. Shale and concealed	180	0	to	200

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* C. W. Hayes, U. S. Geological Survey folios, Kingston, 1892.

† J. M. Safford: Geology of Tennessee, p. 389.

‡ F. H. Bradley, quoted by Killebrew and Safford: Resources of Tennessee, 1874, pp. 200, 201.

	Feet.	Inches.		Feet
16. Heavy bedded sandstone	40	0	to	45
17. Mostly shale	117	0		
18. *Rockwood coal bed* [Sewanee]	3	0	to	4
19. Fireclay, shale, and shaly sandstone	18	0	to	27
20. Coarse to fine and pebbly sandstone, heavy bedded, with 3 beds of shale; in all, 18 feet	154	0		
21. Ferny shale	40	0		
22. *Coal bed* [Soddy]	3	0	to	4
23. Heavy bedded sandstone, mostly conglomerate [Etna, Cliff]	140	0	to	150
24. Clay and sandy shale	180	0		
25. Sandstone	25	0		
26. Gray ferriferous shale	170	0		
27. Sandstone	85	0	to	100
28. Shales	150	0	to	200

The whole of this section belongs to the Pottsville. With the Corbin, which is the Sharon sandstone, one reaches once more the beds equivalent to the northwest Pennsylvania section, of which it is the bottom. No attempt at identification of the higher beds is attempted here, but, as Harriman is on the border of the area showing greatest thickness, one should find at a short distance northwest not less than 1,000 feet of Pottsville above the Corbin (Sharon) sandstone. The thickness of Corbin here is practically the same as in Mr Hayes' Rockwood section. The Bonair in number 20 can not be separated sharply from the overlying and underlying sandstone beds, which replace much of the shales. The coal bed number 22 can hardly be the coal bed of Mr Hayes' Rockwood section at 155 feet below the Sewanee; it is more nearly in the place of the Soddy, which rests on the Etna conglomerate. The identification of number 23 with the Etna conglomerate agrees with that of Professor Bradley, who says that the Etna coal bed is at 15 feet below it. A 2-foot coal bed has been opened in number 24, but its exact position is not given in the extract from which the section was copied. The thickness of measures below the Etna (Cliff) conglomerate is 643 feet, and the whole thickness of the Lookout, including what may be taken as the Bonair proper, is about 925 feet. From this should be taken probably 100 feet at the bottom belonging to Campbell's Pennington (Shenango) shales, so that the thickness may be taken approximately at 800 feet.

The coal at Rockwood and Harriman is badly contorted. Messrs Killebrew and Safford say that the bed at Rockwood dips 35 degrees northwest, and "is remarkable for the immense curled masses of coal rolled up between the 'horsebacks' and attaining a thickness of from 60 to 110 feet."* Mr Hayes reports that at Harriman the dip is about 45 degrees northwest, and that the coal is crushed into rhomboidal blocks with polished surfaces.

At Harriman one is on the border of Safford's northeastern district, where the greatest thickness of Coal Measures is found. He made practically no systematic study here, his volume containing only an incomplete section in northern Anderson county. Much of the region was examined by Mr Keith, who has published only a brief synopsis of his work. Professor Bradley made a preliminary section in Anderson county. It is unfortunate that so little of detail is available for this area, in which, as proved by Mr Campbell's work in southwest Virginia and by the work of Professor Crandall in Kentucky, so great changes take place in the Pottsville. Enough, however, is available to enable one to follow out the main horizons and to recognize the more important conditions.

Mr Keith's work, beginning in eastern Fentress county, where it is in contact with that of Mr Campbell, extends across to the eastern escarpment, where it is continuous with that of Mr Hayes at the south. His division of the section within his area is

	Feet
1. Anderson sandstone remaining	550
2. Scott shales Largely shale, but containing some sandstone, several coal beds, of which one near the bottom is especially important and sometimes 6 feet thick.	500 to 600
3. Wartburg sandstone A bold sandstone at top and bottom with other sandstone beds, some of them 60 feet thick. Fully one-half of the mass is sandstone. It contains certainly five coal beds.	500 to 600
4. Briceville shales Bluish gray to black, argillaceous to sandy shale, with thin sandstones and several coal beds.	200 to 650
5. Lee conglomerate	400 to 1,200

It is sufficiently clear that in Fentress and in western Morgan the Rockcastle is taken as the top of the Lee, which is represented on the general chart of the Briceville folio as embracing the Lookout and the lower part of the Walden. The Lookout closes with the Bonair, which is well marked in eastern Fentress, having been reached in borings near Rugby. The Briceville shales overlie the Rockcastle and decrease westwardly, being only 200 feet thick in Fentress, where they underlie the Corbin sandstone, the top of the Lower Pottsville. Mr Campbell finds them only 125 feet thick in western and northern Fentress. The Corbin sandstone, then, is the bottom prominent sandstone of the Wartburg, above which should come the Sharon and Mercer, or Upper Pottsville. The upper or great sandstone of the Wartburg holds the place of the great sandstone underlying the Hunnewell or Tionesta coal bed of Kentucky and Ohio, and that coal bed is to be looked for in the important bed reported by Mr Keith at the bottom of the Scott shales. In Fentress, except at the extreme east, in the western third of Morgan, and in northwest Scott, rocks higher than the Rockcastle are practically wanting; in eastern Morgan and Scott the surface rocks are mostly Briceville, though, especially in Morgan, considerable areas of Wartburg and insignificant areas of Scott remain. In Anderson and Campbell, reaching to the eastern escarpment, those higher groups remain in considerable patches, but at 2 or 3 miles back from the escarpment.

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*J. B. Killebrew and J. M. Safford: Resources of Tennessee, p. 197.

The Lee conglomerate thickens very rapidly toward the east. At Rugby, in the extreme north of Morgan, where the Bonair is 80 feet, a boring showed for the whole a thickness of about 500 feet, while at Rugby road, 7 miles south-southeast, it is 700 feet, the increase being chiefly in the Bonair and underlying beds, which are represented by 250 feet of sandstone and conglomerate, suggesting that the Etna (Cliff) conglomerate has been reached in this direction. The interval between Rockcastle and Bonair in this boring is about 350 feet. The Rockcastle is a sandstone, not showing the conglomerate features characterizing it farther toward the west and northwest.

Professor Bradley's section on Coal creek, in Anderson county, is the only one embracing the whole column as found in the area; it was merely preliminary, having been made during a rapid examination for economic purposes, so that it is lacking in detail. A partial section at Coal creek is given by Mr Keith, and another was made by Professor Safford at 3 to 5 miles west from Coal creek. This last, though measured under serious disadvantage, gives important details which are wanting in the others and enables one to reconcile the apparent discrepancies. The section by Professor Bradley is given here with very little condensation.

	Feet.	Inches.		Feet.	Inches
1. Shale and sandstone	200	0			
2. *Coal bed U*	0	6			
3. Shale, Cliff sandstone	80	0			
4. *Coal bed T*	1	8	to	0	1
5. Interval	20	0			
6. *Coal bed S*	3	3			
7. Shales	10	0			
8. *Coal bed R*	1	0			

	Feet.	Inches.		Feet.	Inches
9. Shale and sandstone	10	0			
10. *Coal bed Q*	1	6			
11. Shale, Cliff sandstone	20	0			
12. *Coal bed P*	2	6			
13. Shale, some sandstone	300	0			
14. *Coal bed O*	5	0	to	7	
15. Shale, thin sandstone	350	0			
16. *Coal bed N*					
17. Shales and sandstone	110	0			
18. *Coal bed M*					
19. Shale, sandstone	100	0			
20. *Coal bed L*	2	10			
21. Shale	10	0			
22. *Coal bed K*	2	2			
23. Shale, Cliff sandstone	180	0			
24. *Coal bed J*	3	6			
25. Shale, sandstone	320	0			
26. *Coal bed I*					
27. Shale, sandstone	160	0			
28. *Coal bed H*	2	0			
29. Sandstone and shale	142	0			
30. *Coal bed G*	2	0	to	3	
31. Sandstone	40	0			
32. "Shells"	130	0	to	150	0
33. Laminated sandstone	12	0	to	15	0
34. *Coal bed F*	1	6	to	2	2
35. Shale and *coal*	1	0			
36. Clay	9	0	to	15	
37. *Coal bed E, Coal creek*	4	0	to	5	0
38. Clay	1	0	to	2	0
39. Shale, sandstone	30	0	to	40	0
40. Clay shale	30	0	to	35	0
41. Sandstone	20	0	to	35	0
42. Shale	10	0			
43. *Coal bed D*	1	6	to	2	4
44. Clay and shale	17	0	to	24	0
45. Shale, sandstone	40	0	to	50	0
46. *Coal bed C*	3	0	to	4	0
47. Shaly sandstone	52	0			
48. Heavy sandstone	33	0			
49. Clay shale	57	0			
50. *Coal bed B*	1	6	to	2	0
51. Shale, sandstone	150	0			
52. Heavy sandstone	50	0	to	60	0
53. Sandstones and shales with *Coal bed A*	250	0			

As the area in which the lower portion of the section, that below number 40, was obtained is much disturbed, the measurements are largely estimates and the thickness below number 41 is approximately 675 feet. Professor Safford's section does not extend below the "Wheeler" or "Coal Creek" bed, number 37 of Professor Bradley's section. Mr Keith's measurements below that coal bed, made during his work for the United States Survey, differ materially from that of Professor Bradley. His section is

	Feet.	Inches.	Feet.	Inches
1. *Coal Creek seam*				
2. Shale	40	0		
3. Trace of *coal*				
4. Shale	30	0		
5. *Coal bed*	0	10		
6. Shale	25	0		
7. Trace of *coal*				
8. Shaly sandstone	90	0		
10. Shale	25	0		
11. Sandstone	40	0		
12. Shale	20	0		
13. *Coal bed*	1	8	to 2	6
14. Shale	15	0		
15. Sandstone and conglomerate	110	0		
16. Shale	15	0		
17. Sandstone	50	0		
18. Shale	10	0		
19. *Coal bed*	2	6		
20. Shale	20	0		
21. Sandstone	50	0		

or about 550 feet below the Coal Creek seam. This section is far from reaching the bottom of the Lee, to which Mr Keith is inclined to assign a thickness of 1,100 to 1,200 feet, with number 11 of this section as the top member. It seems preferable to take number 8 as the top and to regard it as the Bonair, with number 15 as the Etna (Cliff) conglomerate. This interpretation would make the Coal Creek coal bed the Sewanee, and a comparison of the sections above that bed confirms the correlation. In all of the sections there is practical agreement as far up as Bradley's "Coal bed I," above which for 320 feet (Bradley) or 350 feet (Safford) no coal beds were seen. Mr Keith's section shows four coal beds in the interval.

The sections by Professor Bradley and Mr Keith were made in the same locality, the lines passing through the Coal Creek mines; but Professor Safford's section was made at 3 or 4 miles westward, though the top of the section was within a mile of the highest point reached by Professor Bradley.

In Professor Safford's section a massive sandstone, 50 to 60 feet thick, is shown at about 190 feet above the Coal Creek (Sewanee) coal bed, or 20 feet above Bradley's "Coal G," while at 235 feet higher, about 480 feet above the Coal Creek, is a great sandstone, 75 to 100 feet thick. This is about 50 feet above Bradley's "Coal I" and 560 feet above the Bonair conglomerate, a decided increase of thickness of measures toward the east, for at Rugby road, 12 or 15 miles west, the interval between Bonair and Rockcastle is about 350 feet. The lower sandstone is evidently that between the Sewanee coal bed and the Rockcastle, which is persistent in all the sections. At 370 feet above this great sandstone, taken to be the Rockcastle, is another, 60 to 90 feet, which is in the place of the Corbin, the top of the Rockcastle formation of Crandall, the Lee formation of Campbell's Kentucky folios, while at approximately 800 feet higher is a massive sandstone, 100 feet thick, capping the peaks in Safford's area and evidently almost immediately underlying "Coal P" of Bradley's section. At about 250 feet below it in Safford's section is a bed of fine coking coal, 6 feet thick and divided by a 6-inch clay parting. This is Bradley's "Coal O," which in his section is 300 feet below "Coal P."

The intervals observed at Coal creek, Harriman, and Dayton may be compared.

	I	II			III
	Feet.	Feet.	Inches.	Feet.	Feet
Coal bed	4	1	6		
Interval	230	193	0		
Corbin	60 to 90	193	0		75
Interval	370	320	0		334
Rockcastle	75 to 100	50	0	to 70	70
Interval	235	180	0	to 200	121
Sandstone	50 to 80	40	0	to 45	25
Interval	190	117	0		75
Sewanee coal bed					

The interval from Sewanee to Rockcastle shows constant increase in northeastward direction, but that from the Rockcastle to the Corbin is practically uniform throughout, and that between the Rockcastle and the coal bed at the top shows no change between Harriman and Coal creek. The section below the Sewanee coal bed shows a similar increase northeastwardly. The Bonair and lower rocks are not more than 800 feet at Harriman. The thickness at Oliver springs, according to Mr Keith, is about 900 feet, but at Coal creek it is 1,100 to 1,200 feet.

This grouping of the measures is of interest not only as showing the relation to the Kentucky coal field, but also as binding the Tennessee work to the detailed studies of Mr Campbell in southwest Virginia. The great sandstone crowning Professor Safford's section is that which underlies the Kentucky "Coal 4." It is Mr Campbell's "Gladeville sandstone" of southwest Virginia. The coal bed above it is the Tionesta of Pennsylvania and Ohio, the Hunnewell and Lower Splint of Kentucky, while that at 300 feet, more or less, below this coal is apparently the number 3 of Kentucky, the Mercer or Elkhorn, and perhaps the Imboden of southwest Virginia; so that in this section by Professor Bradley the whole of the Pottsville and a small portion of the Allegheny are included.*

VIRGINIA

No detailed observations are recorded between Coal creek and northeastern Lee county of Virginia, a distance of 40 miles. At the latter locality one finds the section closely allied to the Elkhorn section of Kentucky.

In the Big Stone Gap area, embracing parts of Lee, Wise, and Scott counties, Virginia, and of Harlan county, Kentucky, Mr Campbell divides the measures into

	Feet
Wise formation	1,276
Gladeville sandstone	120
Norton formation	1,280
Lee formation	1,530

with a still higher formation, which does not concern the present paper.

In Lee county, at a few miles southwest from the limits of Mr Campbell's area, Stevenson obtained a section of the Lee formation along Penningtons gap, where the rocks are almost vertical and, except in one very tortuous portion of the gorge, well exposed. The intervals were determined by pacing during a very hasty examination, so that while the succession is given correctly, some of the thicknesses assigned are certainly incorrect. The rocks are almost wholly sandstone and conglomerate, with a reported thickness of somewhat more than 1,000 feet, evidently too little, for here one has higher measures than in Mr Keith's Coal Creek section, where the thickness from Bonair downward is given as 1,100 to 1,200 feet. The error is most probably in the estimate of a sandstone mass at about 255 feet below the "Bee rock" or top conglomerate of the formation. Mr Campbell's section in Big Stone gap, somewhat more than 15 miles northeast from Penningtons gap, is in marked contrast with that offered by Stevenson not only in thickness but in composition. It is

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* F. H. Bradley: Report to Coal Creek Mining and Manufacturing Company, 1872, pp. 5–10. This report is quoted in Resources of Tennessee, pp. 207–210.

J. M. Safford: Geology of Tennessee, pp. 401–403.

A. Keith: United States Geol. Survey folios. Briceville, 1896; Wartburg, 1897.

	Feet.	Inches
1. Massive sandstone, "Bee rock"	95	0
2. Black carbonaceous shale	31	0
3. Dark sandy shale	14	0
4. Brown and green shale	6	0
5. Concealed	85	0
6. Dark shale	210	0
7. Sandstone, with a few bands of shale	566	0
8. *Coal bed*	4	10
9. Shale, with a few bands of sandstone	112	0
10. *Coal bed*	3	0
11. Shale	150	0
12. Conglomerate	250	0

The conglomerate at the bottom, also present in Penningtons gap, where it is certainly much thinner, is a new member or at least it can not be recognized in descriptions of sections farther south. It may be the lowest sandstone of Bradley's Harriman section, which rests on shales, of which much belongs to the Pennington (Shenango) of Campbell, and it may be the lowest conglomerate referred to by Mr Keith. A coal bed at 20 to 30 feet below this conglomerate is described by Campbell as a very fair cannel. Accepting the reference of the conglomerate as given above, this coal bed would be at the place of Bradley's Coal A, and some of the shales assigned by Campbell and Stevenson to the Lower Carboniferous should be placed in Pottsville.

The Norton formation extends upward to a bold sandstone, the Gladeville, which was traced through Lee and Wise counties of Virginia and Harlan of Kentucky. The thickness of Norton, as given by Campbell, is fully 500 feet greater than Stevenson's estimate, obtained by tying together two sections which evidently were not continuous. Mr Campbell gives two measured sections in the western part of Wise county, which together show the upper part of the Norton, and Stevenson gives one in Lee county for the lower portion, the thicknesses being largely estimates. Though not continuous, these enable one to get such understanding of the succession as is necessary for comparison with adjacent areas in Tennessee and Kentucky. The section by Mr Campbell includes the Gladeville sandstone and some higher beds which are important in this connection. It is

	Feet.	Inches
1. Sandstone	45	6
2. "*Cannel bed*"	6	6
3. Thin bedded sandstone	29	0
4. *Upper Splint bed*	1	6
5. Concealed	58	6
6. Shale	16	6
7. Sandy shale	13	6

	Feet.	Inches.		Feet.	Inch
8. *Lower Splint bed*	2	0			
9. Gladeville sandstone	122	0			
10. *Coal bed*	2	0			
11. Shale and concealed	11	0			
12. *Kelly coal bed*	1	6			
13. Interval	75	0			
14. *Imboden coal bed*	6	7	to	13	1
15. Concealed	70	0			
16. Sandstone	20	0			
17. *Coal* and clay	4	8			
18. Shale	10	0			
19. Sandstone	105	0			
20. Shale	110	0			
21. *Coal bed*	0	8			
22. Sandstone	10	0			

showing in all about 530 feet of the Norton. In Stevenson's section at Penningtons gap traces of coal were seen at 25 and 150 feet above the "Bee rock," while at 235, 318, 380, and 417 feet are beds which sometimes attain workable thickness. A massive sandstone is present at about 325 feet above the "Bee rock."

In Harlan county of Kentucky, along the foot of Pine mountain and southward, the Norton appears to hold no important bed of coal, aside from that immediately underlying the Gladeville sandstone. Shales 375 feet thick overlie the Lee formation, with a 1-foot coal bed at the top, immediately underlying a massive sandstone, which is a notable feature in the topography, and clearly the same with at 325 feet above the Lee in Penningtons gap. The Gladeville sandstone is a marked feature in valleys on the southeast side of the county, and the coal bed underneath it becomes at times 5 feet thick. The Lower Splint coal bed resting on the Gladeville varies greatly, but is persistent and of great commercial importance. The Upper Splint is from 65 to 100 feet above the Lower, and the "Cannel" is 21 to 60 feet higher. On Little Black mountain the Cannel is 150 to 160 feet above the Lower Splint. The "Imboden" coal bed, though attaining great thickness in western Wise county, becomes insignificant in Lee, where it was not identified positively by Mr Campbell. Eastward it was followed to very near the line of Dickenson and Russell counties. The Cannel and Splints overlying the Gladeville sandstone were traced by Mr Campbell to the Dickenson line, about 20 miles from Pound gap, in the Elkhorn region of Kentucky.

Mr Hodge found a persistent fossiliferous limestone, 1 to 3 feet thick, at about 725 feet above the Imboden coal bed in Little Black mountain of Wise county.

In the extreme eastern part of Wise county Mr Campbell measured a section which shows the relations of the chief horizons of the Norton.

	Feet.	Inches.		Feet.	Inches
1. Gladeville sandstone					
2. Interval	150	0			
3. *Imboden coal bed.*	4	5			
4. Interval	250	0			
5. *Upper Banner coal bed*	3	0	to	7	
6. Interval	100	0			
7. *Lower Banner coal bed*	1	6	to	4	4
8. Interval	225	0	to	285	
9. *Kennedy coal bed*	1	0	to	9	
10. Interval	340	0			
11. *Tacoma coal bed*	3	4	to	4	4
12. Interval	90	0			
13. *Jawbone coal bed*	4	4	to	8	8
14. Interval to Lee formation	150	0			

giving in all somewhat more than 1,200 feet for the Norton. The coal beds numbers 11 and 13 correspond to beds seen by Stevenson in Penningtons gap, where the latter is sometimes of workable thickness. The other beds below the Imboden are usually thin in Lee and western Wise. Careful and detailed observations were made in this area by Messrs McCreath and d'Invilliers, whose results will be utilized in another connection.*

In attempting to correlate these Virginia deposits with those already described in Tennessee, one is at some disadvantage because no available information exists for the region along the easterly border from Coal creek northeastward; the more so because only two imperfect sections of the Lee formation have been obtained within the Stone Gap area. It is possible only to recognize the chief members of the column, and detailed correlations must be left in great part for others.

Mr Campbell's Lee formation is strictly equivalent to Mr Keith's Lee conglomerate of the Wartburg quadrangle in Tennessee, the top member of which is the Rockcastle of Mr Campbell's section on the west side of the Cumberland plateau in that state and in Kentucky. This is the "Bee rock" of the sections in Penningtons and Big Stone gaps. The sandstone of Penningtons gap and of Harlan county, which belongs in the interval above the "Tacoma" coal bed of eastern Wise and western Russell, from 325 to 375 feet above the Rockcastle ("Bee rock"), is the Corbin of Campbell and the Sharon sandstone of Pennsylvania and Ohio. It is of interest to note that this interval has shown little change for more than 100 miles along the eastern outcrop. The Bonair and Etna (Cliff) are distinct in Penningtons gap, but they are not separate in the Big Stone Gap section. The Gladeville sandstone, 800 to 900 feet above the Sharon (Corbin), is the great sandstone underlying the Kentucky Coal 4, the Hunnewell cannel, and the Tionesta of Ohio and Pennsylvania. The Imboden coal bed is evidently at the horizon of Bradley's Coal bed O; the Lower Splint is his Coal bed P, and the interval in western Wise is practically the same as on Coal creek, the Gladeville sandstone in each locality being about 800 feet above the Sharon (Corbin). There are some additional details which confirm these identifications. It will be remembered that Professor Crandall, in his description of the Pound Gap region, showed a succession very similar to that of the Big Stone Gap area. His provisional section for the Elkhorn region may be compared with that at Big Stone gap:

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* J. J. Stevenson: Geological reconnaissance of parts of Lee, Wise, Scott, and Washington counties, Virginia. Proc. Amer. Phil. Soc., vol. 19, 1881, pp. 229, 230, 238, 239, 249, 250. The names *Cannel*, *Upper Splint*, *Lower Splint*, *Kelly*, and *Imboden*, applied to the coal beds in this paper, have been retained by Mr Campbell, though the upper three beds do not retain throughout the area the characteristics upon which the names were based. Stevenson's work in this region was a mere reconnaissance and in no sense "a careful study," as some have supposed. The whole time spent in the coal area within three counties was less than three days.

M. R. Campbell: Geology of Big Stone Gap coal field of Virginia and Kentucky. Bulletin U. S. Geol. Survey no. 111, 1893, pp. 39, 41–46, 63, 69; U. S. Geol. Survey folios, Estillville, 1894; Bristol, 1899.

J. M. Hodge: The Big Stone Gap coal field. 1893, p. 3 (author's edition, Trans. Amer. Inst. Mining Eng'rs).

	Feet.	Feet	
1. Fossiliferous limestone			
2. Interval	210	265	
3. *Cannel*			
4. Interval	150 to 175	21 to 60	
5. *Upper Splint*			
6. Interval	100 to 130	65 to 100	
7. *Lower Splint*			
8. Sandstone	120 to 150	120	Gladeville
9. *Coal bed*			
10. Interval	15 to 40	111	
11. *Elkhorn coal bed*	....	....	*Kelly*
12. Interval	20 to 40	75	
13. *Wright coal bed*	....	....	*Imboden*

with in Kentucky 400 feet and in Virginia 600 feet of shales and sandstones to the Sharon (Corbin) sandstone, these lower beds containing coal beds, some of which become of workable thickness at various localities.

Although Professor Crandall is careful to state that his Elkhorn general section is purely provisional, it suffices to show that the general succession is the same in both localities. Measured sections in neighboring counties of Kentucky show that the intervals above the Gladeville sandstone to the Cannel are larger there than in the Stone Gap region. This decrease southwardly in the Allegheny is a foreshadowing of conditions which will be observed farther north. Below the Gladeville sandstone the increase is very marked, the interval to Sharon increasing from less than 500 to about 800 feet. The succession below the Gladeville sandstone would make the first coal bed equivalent to the "Kentucky 3*a*," and the "Elkhorn" equivalent to the "Kelly;" but the interval from Gladeville to Elkhorn in the Pound Gap region is much less than farther south in Kentucky. The structure of the bed, its peculiar variations in thickness, the remarkable excellence of the coal—all tend to ally it more closely with the Imboden. At present, however, the sections have not been made across the area, and one can go no farther than to recognize in the Kelly-Imboden horizon the representative of the Mercer beds of Pennsylvania and Ohio, represented in Kentucky by coal 3 and in some portions of the state by coals 3, 3*a*, and 3*b*.

No study of the region immediately northeast or northwest from Wise county has been published; but at about 25 miles from the Wise county line one reaches the extensive area studied by Mr Campbell, beginning with Tazewell and Buchanan counties of Virginia and continuing thence through Mercer, McDowell, Raleigh, and Fayette counties of West Virginia to the New river, and thence along that and the Kanawha river almost to the Ohio. In much of this area, as well as between it and the Kentucky line in West Virginia, one has Dr I. C. White's careful observations, as well as notes by Mr McCreath, some measurements by Mr d'Invilliers in Wyoming and Boone counties of West Virginia, and Mr Lyman's report on the Coal River region of the same state.

The eastern edge of the coal area beyond Wise county swings abruptly toward the east, the direction being but little north of east, whereas in Tennessee as well as in Lee county it is somewhat north of northeast. This change carries one quickly into a region where the sedimentation is different in type, and the tracing of minor horizons, in the absence of sections in Russell and western Tazewell of Virginia, must be somewhat hypothetical. The section for Tazewell, eastern Buchanan of Virginia, and western McDowell of West Virginia, as compiled from Mr Campbell's text, is as follows:

	Peet.	Inches
Tellowa formation:		
1. Sandstone and shale	350	0
2. *Coal bed*	5	8
3. Sandstone and shale	150	0

	Feet.	Inches.	Feet.	Inches
Sequoyah formation:				
4. Sandstone and shale	200	0		
5. *Coal bed*	3	5		
6. Sandstone and shale	75	0		
7. *Coal bed*	2	5		
8. Sandstone and shale	175	0		
Dotson formation:				
9. Coarse sandstone	120	0		
10. Shales, thin *coal bed*	60	0		
Bearwallow formation:				
11. Conglomerate	60	0		
Dismal formation:				
12. Sandstone and shale	145	0		
With *coal*	4	8		
13. Sandstone or conglomerate	100	0		
14. Sandstone and shale	140	0		
15. *Coal bed*	4	0	to 8	
Raleigh formation:				
16. Sandstone	100	0		
Welch formation:				
17. Sandstone, shale, and two *coal beds*	250	0		
18. *Coal bed*	1	0	to 2	
19. Sandstone and shale	100	0		
20. *Upper Horsepen coal*	2	0	to 8	
21. Sandstone and shale	60	0		
22. *Middle Horsepen coal*	1	0	to 4	
23. Sandstone and shale	110	0		
24. *War Creek coal*	4	0	to 5	
25. Sandstone and shale	120	0		
26. *Lower Horsepen coal*	4	9		
27. Sandstone and shale	150	0		
Pocahontas formation:				
28. *Pocahontas coal*	3	8	to 10	
29. Sandstone and shale	60	0		
30. *Coal bed*	2	6	to 3	8
31. Sandstone and shale	150	0		
32. *Coal bed*	2	8		
33. Sandstone and shale	150	0		

The Tellowa and Sequoyah are the Gladeville sandstone and the upper Norton, with perhaps the lower beds of the Wise. The Dotson sandstone is the Sharon (Corbin), and the Raleigh is the Bonair. The conditions in the lower half of the column are much in contrast with those farther southwest. Here are no conglomerates, and even the sandstones are not coarse. The contrast is even more noteworthy below the Pottsville, for in Wise county the Shenango (Pennington) shales are at most 1,300 feet, whereas in eastern Russell and in Tazewell they are represented by more than 3,000 feet of fine sediment.

Mr Campbell offers a somewhat different grouping farther east, which should be noted here, that comparisons may be made the more easily:

Sewell formation.
Raleigh sandstone.
Quinnimont formation.
Clark formation.
Pocahontas formation.

The Sewell formation includes the Dotson, Bearwallow, and Dismal; the Quinnimont and Clark are subdivisions of the Welch, the line being drawn under the "Upper Horsepen" coal bed, which on New river has long been known as the "Quinnimont" coal bed. The "Clark" is bounded by two well marked sandstones, numbers 21 and 27. The higher formations, Sequoyah and Tellowa, belong to the Kanawha formation of counties farther north.

The Tellowa and Sequoyah extend eastward only into northern Buchanan and western McDowell, and the important coal bed of the former is mined in northwestern McDowell. It is at somewhat more than 600 feet above the Dotson (Sharon) sandstone, and evidently represents the Kelly-Imboden horizon. Only the Dismal or lower part of the Sewell extends eastward beyond the central line of McDowell; the formation covers the higher areas in eastern Buchanan, western McDowell, northern Russell, and western Tazewell. Its lower coal bed, the Sewell of more northern localities, the Sewanee of Tennessee, has been opened at many places. The Raleigh sandstone varies from 80 to 100 feet; though retaining its thickness and identity, it becomes shaly sandstone west from the line of central McDowell and Tazewell, but eastwardly it becomes coarser and occasionally conglomerate. It forms the escarpment of the high hills in eastern McDowell and Wyoming counties known as Flat Top, where it is about 80 feet thick, massive, and coarse.

The Horsepen group of coals, numbers 20, 22, 24, and 26, belong, with the exception of the Upper, to the Clark formation, and attain their maximum near the line between Tazewell of Virginia and McDowell of West Virginia. The "Pocahontas" coal bed has been traced along the easterly outcrop in Tazewell and Mercer counties by means of openings for the Flat Top Land Association. It is from 4 to 12 feet thick and everywhere yields a coal of remarkable purity.

The relations of the lower beds are shown in two sections. One reported by Mr McCreath from northeastern Tazewell is

	Feet.	Inches
1. Concealed measures	40	0
2. *Coal 7*	2	0
3. Concealed	20	0
4. *Coal 6*	1	6
5. Concealed	80	0
6. *Coal 5* and dirt	4	6
7. Concealed	91	0
8. *Coal 4*	2	0
9. Concealed	90	0
10. Sandy fireclay	6	0
11. *Coal 3, Pocahontas*	11	3
12. Fireclay	6	0
13. Shales and sandstone	61	0
14. *Coal 2* and shale	4	0
15. Concealed	12	2
16. Gray sandstone	15	4
17. *Coal 1*	1	0
18. Sandstone, some shale	67	10
19. Sandstone, *coal* streaks	8	8
20. Shale and sandstone	294	9

to red shale. The section does not reach to the top of the Clark formation. The thickness of the Pocahontas formation is about 120 feet greater than that assigned by Mr Campbell, but the difference is due probably to choice of strata for the bottom. Doctor White gives a section supplemented by a boring at Welch, in north central McDowell, of West Virginia, much longer than that by Mr McCreath :

	Feet.	Inches.		Feet.	Inches
1. Concealed	150	0			
2. *Coal*	2	6			
3. Shales, sandstone, and concealed	40	0			
4. *Coal*	2	0			
5. Shales and concealed	60	0			
6. *Coal bed, "Welch"*	3	1			
7. Shales and concealed	10	0			
8. Raleigh sandstone	190	0			
9. Shales and concealed	160	0			
10. *Coal, Quinnimont*	1	6	to	2	6
11. Sandstone and concealed	180	0			
12. Sandstone and slate	38	0			
13. *Coal* and bone	0	11			
14. Sandstone and shale	117	7½			
15. *Coal bed*	0	9			
16. Sandstone and slate	142	6½			

	Feet.	Inches
17. *Coal 4*	3	5
18. Sandstone and shale	64	4
19. *Coal 3, Pocahontas*	5	2
20. Sandstone and slate	27	5½
21. *Coal,* slate, and bone	1	9
22. Slate and sandstone	10	10½
23. *Coal bed 2*	0	7
24. Slate and sandstone	47	0
25. *Coal bed 1*	0	9
26. Sandstone and slate	202	2

to red beds of the Mauch Chunk, giving 295 feet for thickness of the Pocahontas and 707 for the Clark and Quinnimont. If the tentative identification of the Quinnimont coal bed be correct, the Quinnimont formation shows a notable decrease and the Clark formation an equally notable increase. As the total of both is very nearly that assigned by Mr Campbell, it may be better for the present to look on the coal bed number 10 as one of the smaller beds of the formation, with the Quinnimont to be sought for in the largely concealed interval, number 11. Doctor White suggests that numbers 2 and 4 may represent the "Sewell" coal bed, a wholly probable suggestion, as here one is on the border of the area in which subdivision of coal beds is as much the rule as in other regions it is the exception. The section below number 12 was obtained in a boring. As Welch is at least several miles from any outcrop of the Pocahontas, the record connects the southern area of that bed with the Guyandotte area at the north, where it again comes to the surface and is commercially important.*

WEST VIRGINIA

McDowell and Mercer counties, to which reference has been made already, are in West Virginia. Farther north in this state, in Wyoming, Raleigh, and Fayette, higher rocks are reached, so that one finds at the top the Charleston sandstone of Campbell, about 300 feet of thick sandstones broken by important coal beds; the Kanawha formation, a mass of shales, sandstones, and strangely varying coal beds, in all more than 1,000 feet thick, with the Sewell, now 600 to 800 feet. The Raleigh, Quinnimont, Clark, and Pocahontas are still present, but all showing changes.

Mr Campbell points out that these lower formations, generally speaking, retain their thickness and characteristics as far north as southern

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* A. S. McCreath: Mineral Wealth of Virginia, 1884, p. 107.
M. R. Campbell: U. S. Geol. Survey folios, Pocahontas, 1896; Tazewell, 1897.
I. C. White: West Virginia Geol. Survey, vol. ii, 1903, p. 620.

Raleigh. The plane of separation between the Pocahontas and Clark was drawn on top of the Pocahontas coal bed, and this division is clear on Flat Top, in Mercer, as well as along the Guyandotte river in southern Raleigh and Wyoming; but that coal bed becomes insignificant northward, and the two formations near New river are united by Mr Campbell into the Thurmond, which there is but 450 or 500 feet as against about 750 in southern Raleigh. Along the Guyandotte river the Pocahontas coal bed is important, and Mr d'Invilliers has described it in detail. Other beds of some importance are present there in both the Clark and the Pocahontas, but near New river, in Fayette county, the Thurmond appears to contain no coal bed of any value whatever.

The Quinnimont, equivalent to the upper Welch of the Tazewell-McDowell area where it is more than 300 feet thick, decreases northward, as does the Thurmond, and is only 180 feet on New river. The Quinnimont coal bed rests on the heavy sandstone at the top of the Thurmond, and the "Beckley" coal bed is directly under the Raleigh sandstone. Two other beds are in the interval, but they have not been exploited. The Quinnimont bed, named by Fontaine many years ago, is the same with the Fire Creek bed of lower New river; it is extremely variable. In southern Raleigh it is unimportant, but in southern Wyoming, near the Raleigh line, as well as in the central part of the county, it is valuable. On New river it is important from Quinnimont to Sewell, 10 or 12 miles, but below Sewell Mr Campbell did not recognize it, though several miles farther on it was found by Doctor White. The "Beckley" coal bed is workable only in northern Raleigh, but either thin coal or black shale is present at almost every exposure of its horizon. These persistent beds below the Raleigh (Bonair) sandstone bear much resemblance in their position and in their persistency to the beds between the Bonair and Etna sandstones in Tennessee, and it is possible, one might almost say probable, that the persistent sandstone at the top of the Clark or Thurmond, which has been seen in all the sections from eastern Russell to New river, may prove to be the Etna (Cliff) sandstone.

The Raleigh (Bonair) sandstone is less thick in southern Raleigh than at Welch, in McDowell county, but it thickens northward until it becomes 150 feet or more near New river. Eastward and southeastward from that river, in Fayette county, it decreases and becomes unimportant within a few miles; but it maintains itself northward along New river, and westward it is easily recognized in Raleigh and Wyoming wherever its place is exposed.

The Sewell formation, 600 to 700 feet thick, has as its highest member the Nuttall (Sharon, Corbin, Dotson) sandstone, which along New river is a massive conglomerate, 150 to 200 feet thick, forming cliffs from Nuttallburg to Gauley bridge, at 375 feet above the Raleigh. West from New river, in Fayette county, the upper portion of this sandstone loses its massiveness and coarseness within a few miles, but the lower portion remains conglomerate for 12 miles. In western Fayette, in Boone, and northern Raleigh the whole deposit becomes more or less a shaly sandstone and soon loses its distinctive features. The coal beds of the Sewell formation are at least four, but only one, that at from 40 to 90 feet above the Raleigh, is of commercial importance. This, the Sewell of New river, the Sewanee of Tennessee and Alabama, is about 4 feet thick at Sewell, on New river, and increases somewhat toward the west, but it diminishes eastward and northward in Fayette county, becoming only 2 feet thick at the Hawksnest, 15 miles northwest from Sewell.

The plane of separation between Sewell and Kanawha is sufficiently sharp along New river, where the Nuttall (Sharon, Corbin, Dotson) sandstone is characteristic; but westwardly, where that rock becomes indefinite, the two formations are continuous. Many of the coal beds familiar to those living along the Kanawha river have been recognized here; but reference to them must be deferred until after the section along the Kanawha river has been studied, and the relations of the Charleston sandstone will be reviewed at the same time.*

More than sixty years ago Professor William B. Rogers determined that the coal rocks of New river, in Fayette county, belong to his formation XII, the Seral conglomerate of the Pennsylvania column; but his published notes are very brief. The first detailed descriptions known to the writer were given by Professor Fontaine, who applied the name "New River series" to the rocks in question. His section near Quinnimont extends from the Raleigh sandstone to the Lower Carboniferous and shows

	Feet
Raleigh sandstone	150 to 200
Quinnimont formation	198
Clark formation	326
Pocahontas formation	543

The Beckley and Quinnimont coal beds are shown in his section. The top and bottom sandstones of the Clark are defined sharply, the lower being a massive bed, and the thickness of the formation is 326 feet, or almost 50 feet less than that given by Mr Campbell for southern Raleigh. The excessive thickness assigned to the Pocahontas is due to including beds at the bottom which later observers have referred to the

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* M. R. Campbell: U. S. Geol. Survey folios, Raleigh, 1902.

E. V. d'Invilliers: Geological Report on the West Virginia and Ohio Railroad Line, 1886, pp. 8, 12, 13, 14.

Lower Carboniferous, and the thickness thus corrected is about 250 feet. The four coal beds of the Clark are all thin, and the Pocahontas coal bed, immediately underlying the bottom sandstone of the Clark, is 2 feet 6 inches thick. A section at Sewell reaches to the Nuttall sandstone. It shows the Sewell (Sewanee) coal bed at 50 feet above the Raleigh sandstone, and another bed at 190 feet higher. Two coal beds are shown in the Quinnimont, the upper one at 100 feet above the Quinnimont coal bed and 78 feet below the Raleigh. Four coal beds are present in the Clark portion of the column at 100, 112, 152, and 208 feet below the Quinnimont bed. The Sewell (Sewanee) coal bed is irregular and known to the miners as the "conglomerate seam." Its floor is not the usual fireclay, but is "a curious conglomerate, consisting of fragments of fine-grained gray sandstone and very fine gray shale, cemented together by shaly matter colored with coaly matter." The roof shales contain an abundant flora. Doctor White's section at Sewell gives 982 feet as the thickness below the Sewell coal bed.*

The first complete section of the Lower Pottsville was made by Doctor White at Nuttallburg on New river at 10 or 12 miles below Sewell. This was measured in 1884, but revised afterward and republished in 1903. It is

	Feet.	Inches
1. Sandstone, massive, pebbly	110	0
2. Shales	60	0
3. *Coal*	1	0
4. Sandy shales and sandstone	75	0
5. Sandstone	25	0
6. Black slate	2	0
7. *Coal*	1	0
8. Shales and sandstone	75	0
9. *Coal*	0	10
10. Shales and sandstone	50	0
11. *Coal*, Sewell, Nuttall	3	6
12. Shales and slates	75	0
13. Massive sandstone, Raleigh	155	0
14. Slates, dark	10	0
15. Concealed and shales	120	0
16. *Coal*	3	5
17. Shale and sandstone	130	0
18. *Coal*, Quinnimont	4	5
19. Shale and sandstone	35	0
20. *Coal*, slaty	2	4
21. Shales	40	0

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* W. M. Fontaine: Great Conglomerate on New river, West Virginia. Amer. Jour. Sci., 1874, pp. 465, 573, 574. Conglomerate Series of West Virginia. Amer. Jour. Sci., 1876, vol. xii, pp. 279 et seq.

I. C. White: Catalogue West Virginia University, 1884, p. 89.

	Feet.	Inches
22. *Coal*	1	5
23. Shales	10	0
24. Concealed	30	0
25. Massive sandstone	125	0
26. Concealed and sandstone	60	0
27. Massive sandstone	140	0
28. Conglomerate and sandstone	55	0

or 1,400 feet to the top of the Mauch Chunk red shales. Grouping the beds for comparison with localities at the south, one has

	Feet
Sewell formation	478
Raleigh sandstone	155
Quinnimont formation	268
Clark and Pocahontas (Thurmond)	499

The only decrease is in the Sewell; the Quinnimont shows a decided increase. A great change has taken place in the lower part of the column. Fontaine's section near Quinnimont shows much shale and flaggy sandstone in the lower Clark and in the Pocahontas, where massive sandstones predominate in the Nuttallburg section. The four coal beds of the Sewell formation persist, though the Sewell (Sewanee) bed is the only one of value. Three beds are exposed in the Quinnimont and the upper two beds of the Clark still persist. The place of the Pocahontas is in the concealed interval, number 26, but no trace of it or of the other low coals is reported by Doctor White.*

The Nuttall (Sharon, Corbin) sandstone forms cliffs along New River canyon to Kanawha falls, about 12 miles northwest from Nuttallburg. There, according to J. B. Rogers, it is still more or less conglomerate. It finally passes under the Kanawha river (formed by union of New and Gauley rivers) at 3 miles below the falls, not far above the mouth of Armstrong creek, where Doctor White obtained a section which will be referred to further on. From the falls westward and northwestward along the river one has to do with the Kanawha formation almost to Charleston, beyond which the Charleston sandstone and higher beds are the surface rocks. To prepare a generalized section of the Kanawha formation as it occurs along the river is very difficult, owing to the extreme variability of the coal beds and of the intervals separating them, conditions to which Professor W. B. Rogers first called attention 63 years ago and which were emphasized by Professor Fontaine 30 years ago. The general succession may be given as follows:

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*I. C. White: U. S. Geol. Survey Bulletin, no. 65, p. 197; West Virginia Geol. Survey, vol. ii, 1903, p. 617.

	Feet.	Inches.	Feet
1. Black Flint	7	0	to 12
2. Shales	1	0	to 25
3. *Cannelton* or *Stockton coal bed*			
4. Shales and sandstone	75	0	to 100
5. *Coalburg coal bed*			
6. Shales, massive sandstone	75		
7. *Winnifrede coal bed*			
8. Shales, sandstone with thin coal beds	200	0	to 250
9. *Cedar Grove coal bed*			
10. Shales	50	0	to 75
11. Campbells Creek limestone	1		
12. Shale, sandstone	40	0	to 50
13. *Campbells Creek coal bed*			
14. Shales, sandstone with *Brownstown coal bed*	75	0	to 100
15. Stockton cement	2	6	
16. Shales	45	0	to 50
17. *Eagle coal bed*			
18. Shales	20		
19. *Little Eagle coal bed*			
20. Shale, sandstone	55		
21. Eagle limestone	1		
22. Shale, sandstone	120		
23. Siliceous limestone	1		
27. Interval	100		

to the Nuttall sandstone. As will be seen, the extent of variation in the intervals exceeds greatly the figures given in the table.

There is little of interest below the Eagle limestone of I. C. White. Several thin coal beds are in the interval, but they are not present in some of the sections, though some of them may be represented by black shales at several horizons. The Eagle limestone, commonly known as the " black marble," is black, more or less carbonaceous, blocky, impure, with cone-in-cone structure, and is richly fossiliferous, as are the shales inclosing it.

The " Eagle " coal bed of I. C. White, mined just east from the Fayette-Kanawha line, passes under the Kanawha at a short distance west from that line, but is brought up again by a gentle anticline. It is evidently the bed on Smithers creek referred to by Rogers as 90 feet below the " Thick " coal bed and separated by yellow shales from a richly fossiliferous limestone. Like the " Little Eagle " below, it is a soft, coking coal, with no trace of splint.

The Stockton or Cannelton cement bed, at most 50 feet above the Eagle coal bed, and 2 feet 6 inches thick, is not always a continuous bed, but sometimes occurs in lenticular masses, separated by 1 to 10 feet. It has cone-in-cone structure and is apparently non-fossiliferous.

Rogers refers to it as occurring in separated masses farther down the river, on Rider and Hughes creeks, where it underlies yellow shales with nodular iron ore.

The variability of the interval between the "Campbells Creek" and Eagle coal beds is shown by the following measurements by Doctor White at Cannelton and Brownstown, 16 miles apart:

	Feet.	Inches.	Feet.	Inches
1. *Campbells Creek coal bed*				
2. Sandstone and shales	40	0	74	0
3. *Brownstown coal bed* and partings	20	6	2	0
4. Shales and sandstone	40	0	70	0
5. Limestone	1	0	1	0
6. Shales	10	0	45	6
7. *Eagle coal bed* and partings	26	2	3	0
Total	137	8	195	6

At Brownstown the Eagle coal bed is 98 feet above the Nuttall sandstone, but at Armstrong creek the vertical distance is 290 feet. Three miles below Brownstown, 6 miles above Charleston, the whole interval from Campbells Creek coal bed to the Nuttall is but 132 feet, a decrease of 34 feet per mile. The contrast between conditions above and below the Eagle at Armstrong and Brownstown is worthy of notice; for while the interval to the Nuttall decreases almost two-thirds in 16 miles, that above to the Campbells creek increases almost one-half. The Brownstown coal bed is unimportant and disappears at a little way below the Brownstown locality.

The Campbells Creek coal bed is one of the most persistent as well as most variable beds in the formation. Like the coals below, it is a soft coking coal, showing no splint, except a thin streak in one of its divisions. On Gauley mountain, in Fayette county, near the eastern outcrop, it is 11 feet thick, with thin partings. On Armstrong creek, in Fayette, it is in six benches, distributed through 22 feet 4 inches, and the top of the bed is 568 feet below the Black Flint. Near Cannelton, 3 or 4 miles lower down the river, Doctor White's section shows the lower portion of the bed 5 feet thick at 541 feet below the Flint, with the overlying 500 feet concealed. The bed here was described by Professor Rogers as Stockton's 7-foot seam. Mr Ridgway's section at the same place, made upward of sixty years ago, when exposures were almost complete, shows the bed in seven benches, distributed in 85 feet of vertical section, the thick coal at the bottom being at about 550 feet below the Flint. At Coal valley, a short distance lower down the river, the interval to the thick coal at the bottom is 640 feet. Professor Ansted's section on Paint creek does not extend down to this coal, but Mr Maury's on the same stream shows a very complex structure. In this part of the Kanawha valley the main upper and lower divisions of the Campbells Creek bed are so widely separated that they have received different names, the upper being known as the " Peerless " and the lower as the " Blacksburg," or number 2 gas coal. At Winnifrede junction the two beds are 26 feet apart and at 9 miles above Charleston 20 feet. From this locality northwestward the partings become thinner, until on Campbells creek the Peerless and Blacksburg are mined as one bed, with 1-inch partings. The identity of the section is proved by the persistent Campbells Creek limestone above and the Cannelton cement below, which appear in most of the measured sections. The splint layer of the Campbells Creek coal is in the upper bench of the Blacksburg, or lower division. The variations in this bed have been given in detail because they suffice to exhibit the changes shown to a greater or less extent by all the principal coal beds of the Kanawha formation in this region. These variations have been studied by Doctor White during almost twenty years, and his conclusions are shown by a great number of vertical sections to be beyond question.

The Campbells Creek limestone of I. C. White is persistent in the shales overlying the Campbells Creek coal bed, the interval to the coal bed varying from 10 to almost 50 feet. On Campbells creek, according to Professor Rogers, the shales overlying the coal bed are 40 feet thick, bluish drab in color, and contain what he terms " madreporite," which occurs " in large spheroidal masses, resembling the nodules or septaria of formation VIII. These masses are highly calcareous, constituting in fact a tolerably pure limestone, and generally found within a width of about 10 feet of the slate." He notes the usefulness of this deposit as an aid in tracing the coal bed below.

At from 50 to 165 feet above the Campbells Creek coal bed is the Cedar Grove, Arno, or Trimble coal bed, not a true splint as are the higher beds in great part, not soft " gas " coal, as are the lower beds of the Kanawha formation. The bed is thin, but it appears to be present in a large area, and its coal is always of admirable quality. The shales associated with it are rich in fossil plants. Two hundred to 300 feet of sandy measures intervene between the Cedar Grove and the Winnifrede. No coal beds of any importance are seen in this interval, and such as do appear are usually insignificant. The Winnifrede coal bed overlying the sandstone mass rises from the Kanawha river at 2½ miles above Charleston, where it is 18 to 20 inches thick and 150 feet below the Flint; farther up the river this interval increases to 225 feet. The bed is important toward the west and southwest from the river, having been mined continuously from Kanawha county into Boone, the next west, where Mr Lyman shows its variations. At Winnifrede it is approximately 5 feet thick and consists of alternating layers of splint and gas coal. It is of little value in the upper Kanawha region, but it is present in Ansted's Paint Creek section, and Doctor White recognizes it on the border of Fayette county.

Above the Winnifrede at a variable distance—100 feet near the Fayette line, 75 near Lock number 3, 86 opposite Coalburg, and 50 at 12 miles above Charleston—one reaches the Coalburg coal bed, which is at an average distance of 80 or 90 feet below the Flint; but at times the interval is less than half that distance, while in others it approaches 150 feet. The bed varies greatly, though not to the same extent as the Campbells Creek bed. At 3½ miles above Charleston it is mined as one bed, there being three benches with partings of 2 inches and 2 feet respectively; but nearer Charleston the benches are separated by 25 to 30 feet of shale and sandstone. The partings thicken up the river; then disappear; once more thicken, but again diminish, so that at Coalburg the bed is important. It is the "Thick bed" of Ansted's Paint Creek section, and Maury, in the same area, assigns to it a thickness of 11 feet. In the three benches at Coalburg, Stevenson thought he saw the three thin beds near the Kanawha salines, but this was a mere hazard which chanced to be true. The bed is characterized by a peculiar bony slate known as "niggerhead." The coal is comparatively good at one locality near the Kanawha-Fayette line, though above that, while retaining its thickness, the bed becomes worthless. The "Stockton," or highest coal bed of the Kanawha, is at 5 to 130 feet above the Coalburg. On the Cannelton Coal Company's property the interval varies from 5 to 10, 26, 30, and 75 feet, while 5 miles farther down the Kanawha the interval is from 90 to 130 feet. The Stockton is from 1 to 25 feet below the Black flint. Like the other beds, it shows great variation in structure. It rises from the river bed at a little way above Charleston, whence it has been traced by Doctor White to the eastern outcrop in Gauley mountain within Fayette county. It frequently divides into two beds, known as Stockton and "Lewiston," the latter, the lower, being the splint or cannel bed.

The "Kanawha Black flint" is the highest bed of the Kanawha formation. Long ago its peculiarities aroused the interest of Professor Rogers. It is from 4 to 12 feet thick and is a marked horizon from its eastern outcrop in Fayette county to where it passes under the river above Charleston. At many localities it, as well as the associated shale, contains an abundance of the familiar Coal Measures invertebrates. It disappears quickly southward and almost as quickly northward, along the easterly outcrop, but it is present all along the Elk river into Clay county, where the writer recognized it twenty years ago, and it has been followed by Doctor White along the Elk river and northeastward into Nicholas county, not less than 80 miles by the roads from the Kanawha at Charleston.

Overlying the Black flint is a great sandstone 200 or more feet thick, which contains two important coal beds, the "Number 5 block" and the "Mason," which will be considered in another connection.

The decrease in thickness of the Kanawha and Lower Pottsville in northwesterly direction should be noted. At Armstrong creek, in Fayette county, Doctor White's section gives 1,006 feet for the Kanawha; at 9 miles above Charleston, 801; at 6 miles above Charleston, 641; at Charleston, 573; at 1 mile below Charleston, 450. For the Lower Pottsville, Doctor White's Nuttallburg section gives 1,400; a boring at Winnifrede, reported by Mr Campbell, 960; one at Burning spring, reported by Doctor White, 839; at Charleston, 580.*

Before considering further the relations of the Kanawha formation, one must carry the section westward across West Virginia from Raleigh county to the Kentucky line and northward to the Chesapeake and Ohio railroad between Charleston and the Ohio river. The exposed column in much of this region extends downward barely to the Nuttall sandstone, but records of borings are available with which to complete the sections. The typical section for the upper Kanawha is that obtained on Armstrong creek by Doctor White. This was made originally in 1884, and published in 1891, but it has been revised and recast recently, without change in the measurements; it is given here in the completed form with very slight condensation.

	Feet.	Inches
1. Black flint		
2. Interval	12	0
3. *Coal bed*	3	0
4. Sandstone and concealed	345	0
5. Silicious limestone	1	0
6. Sandstone	25	0

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* References for the Kanawha valley are:

W. B. Rogers: Report Geol. Survey of Virginia for 1839, pp. 127, 128, 129, 132, 133, 135.

D. F. Ansted: Report on the "Wilson Survey" near Great Kanawha river, Virginia, 1855.

T. S. Ridgway: Geological report on Chesapeake and Ohio railroad, 1872.

J. J. Stevenson: Ann. N. Y. Lyc. Nat. Hist., vol. x, 1873, pp. 273, 276.

W. M. Fontaine: The Great Conglomerate on New river, p. 462. The Conglomerate Series of West Virginia, p. 279.

I. C. White: Catalogue of West Virginia University, 1885, pp. 69, 70, 71, 73, 74, 76, 77, 78. U. S. Geol. Survey, Bull. no. 65, 1891, pp. 135, 138, 139, 140, 141, 162, 167, 170, 172, 195, 196, 197. West Virginia Geol. Survey, vol. ii, 1903, pp. 372, 509, 565, 567, 586, 593.

M. R. Campbell: U. S. Geol. Survey folio, Charleston, 1901.

		Feet.	Inches
7.	*Cedar Grove coal bed*	2	5
8.	Shale, sandstone, concealed	165	0
9.	*Coal bed*	1	8
10.	Sandy shales	12	0
11.	*Peerless coal bed*	2	0
12.	Bluish shale	15	0
13.	*Blacksburg coal bed*	5	4
14.	Fireclay, shale, sandstone	40	0
15.	*Coal bed* and shale	4	4
16.	Shale, sandstone	15	0
17.	*Coal bed*	1	2
18.	Concealed and sandy shale	40	0
19.	Silicious limestone	1	0
20.	Shale	10	0
21.	*Coal bed*	2	6
22.	Sandy shale	20	0
23.	*Eagle coal bed*	3	8
24.	Shale, sandstone	20	0
25.	*Little Eagle coal bed*	1	6
26.	Shale, sandstone	55	0
27.	Eagle limestone	1	0
28.	Fossiliferous shale	5	0
29.	Sandstone	75	0
30.	Bituminous shale	2	0
31.	Shale	30	0
32.	Silicious limestone	1	0
33.	Shale, sandstone, and concealed	100	0

The interval from the top of the Stockton coal bed, number 2, to the Cedar Grove is 375 feet, but at 3 miles farther down the river it is 421 feet, where the Coalburg and Winnifrede coal beds are shown. The intervals there are

		Feet
1.	*Stockton coal bed*	
2.	Interval	90
3.	*Coalburg coal bed*	
4.	Interval	100
5.	*Winnifrede coal bed*	
6.	Interval	210
7.	*Cedar Grove coal bed*	
8.	Interval	145
9.	*Blacksburg coal bed*	
10.	Interval	115
11.	*Eagle coal bed*	

The Campbells Creek limestone is not exposed at either locality, but there are many exposures of it between them.*

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*I. C. White: West Virginia Survey, vol. ii, pp. 371, 372, 529.

Doctor White gives two sections, one in central Raleigh, on the authority of Mr Miller, the other made by himself near Oceana, in central Wyoming, almost directly west from the former. These are

Raleigh

	Feet.	Inches
1. Sandstone, shale	98	0
2. *Coal bed* and partings	4	8
3. Shale	43	0
4. *Coal bed* and partings	18	5
5. Sandstone and shale	247	0
6. *Coal bed*	4	0
7. Sandstone	19	0
8. *Coal bed*	0	1
9. Fireclay and shale	37	2
10. *Coal bed*	3	2
11. Fireclay, sandstone, shale	115	6
12. *Coal bed*	0	2
13. Fireclay, shale, and sandstone	91	4
14. *Coal bed* and partings	9	8
15. Sandstone	46	0
16. *Coal bed*	0	3
17. Sandstone and shale	208	0

Wyoming

1. Sandstone and concealed	100	0
2. *Coal bed*	3	8
3. Sandstone and concealed	155	0
4. *Cannel* shale and *coal*	3	0
5. Massive sandstone and concealed	72	0
6. *Coal bed* and partings	27	2
7. Concealed and sandstone	20	0
8. *Coal bed*	0	9
9. Fireclay, sandstone, shale	65	0
10. *Coal bed* and partings	24	9
11. Massive sandstone	100	0
12. Concealed and shale	60	0
13. *Coal bed*	7	7
14. Sandstone and concealed	70	0
15. *Coal bed*	5	8
16. Concealed and shales	65	0
17. *Coal bed*	2	3
18. Shale, sandstone, and two thin *coal beds*	212	0

In each case the section rests on the Nuttall sandstone, and the top is taken to underlie the Charleston sandstone. The Eagle coal bed is easily recognized in numbers 14 and 15 of the respective sections at 254 and 279 feet above the Nuttall (Sharon) sandstone, but the limestones belonging in this interval are apparently absent. In the Raleigh, number 6 is 266, and number 4, 517 feet above the Eagle, not far from the intervals for Cedar Grove and Winnifrede in the upper Kanawha region. Number 10 is 207 feet, only 15 feet more than the interval between the Eagle and Campbells Creek near Brownstown. The condition in Wyoming county leads to the belief that this interval is greatly increased southward, with a corresponding decrease in the interval between the Campbells Creek and the Cedar Grove. Number 10 of the Wyoming section appears to be, almost without doubt, the equivalent of the Campbells Creek, and it is almost 240 feet above the Eagle. The "Cook" or "Big bed" of northern Wyoming has been identified with the Campbells Creek by Doctor White and Mr d'Invilliers, both of whom have given many sections. The bed has been traced for the Guyandotte Coal Land Association around a large area, openings having been made at short intervals, so that there seems to be no room for doubt of its identity with the Campbells Creek. The bed, number 13, has its great thickness only locally, and elsewhere in Wyoming county is very thin. It is not far from the place of the Brownstown, and is evidently at the same horizon with number 12 of the Raleigh section. The Cedar Grove near Oceana is but 86 feet above the Campbells Creek, which is double, triple, or even quadruple, and shows the same tendency to variation as on the Kanawha. The highest beds in both sections are taken to be at the same horizon, and probably represent the Coalburg.

Doctor White gives a section in southern Logan county, almost due west from Oceana, as follows:

	Feet
1. Shales and sandstone	100
2. *Coal bed*	
3. Shales, massive sandstone	300
4. *Coal bed*, large blossom	6
5. Massive sandstone	40
6. Shale, sandstone, and concealed	180
7. *Coal bed*, *Eagle*, large blossom	5
8. Shale, sandstone	55
9. *Coal bed*, *Little Eagle*	2
10. Shale, sandstone, and concealed	140
11. Limestone, blue, impure	1
12. Shales, sandstone, and concealed	75
13. *Coal bed*	1
14. Shale, sandstone, and concealed	85

to massive sandstone. The succession is made sufficiently clear by comparison with the Wyoming section. The interval from the Sharon sandstone to the Eagle coal bed has increased, being 70 feet more than at

Armstrong creek and 80 feet more than near Oceana. Number 4, at 220 feet above the Eagle, is very near the place of the Campbells Creek, and number 2 is very near that of the Winnifrede, the intervals, 220 and 526, showing a small decrease westward. Number 11 is one of the impure limestones below the Campbells Creek coal bed.*

In southern Mingo county, about 20 miles west from the Logan locality, an exposure shows †

	Feet.	Inches
1. *Stockton coal bed*, splint	2	0
2. Interval	100	0
3. *Coal*	Blossom	
4. Interval	150	0
5. *Winnifrede coal*, mostly splint	4	0
6. Interval	160	0
7. *Coal*	2	6

This shows an increased interval between Stockton and Winnifrede, the intervals on the upper Kanawha being 90 and 100 feet there, 100 and 150 feet here.

At Warfield, Kentucky, about 10 miles west of north from the last locality, one has Doctor White's section, already given, but which must be repeated: ‡

	Feet.	Inches
1. Massive sandstone	150	0
2. *Coal* and partings	15	9
3. Concealed, sandstone	25	0
4. Limestone, silicious	1	0
5. Shale, sandstone, and concealed	30	0
6. *Coal, cannel*	2	0
7. Sandstone, concealed	30	0
8. Limestone, silicious	1	0
9. Sandstone, concealed	20	0
10. *Coal*, blossom		
11. Sandstone, concealed	65	0
12. Limestone, silicious	2	0
13. Massive sandstone	20	0
14. *Coal* and shale	0	7
15. Sandstone, shale	40	0
16. Massive sandstone	10	0
17. *Warfield coal*	5	2
18. Sandstone, concealed	45	0
19. Silicious limestone	2	0
20. Shales, sandstones	320	0

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* I. C. White: Bulletin no. 65, p. 147.

† I. C. White: Vol. ii, p. 378.

‡ I. C. White: Bulletin no. 65, p. 146; vol. i, p. 277.

The measurement number 20 was obtained in a boring. Number 2 is identified by Doctor White with the Winnifrede. It is in 4 thin benches separated by shale, and the coal is mostly splint. The Warfield bed is clearly taken by him to be the Campbells Creek, and the suggestion is made that the limestone number 12 may represent the Campbells Creek limestone. The interval here between the Campbells Creek and Winnifrede is 246 feet; in Logan it is 300. These are coals 1 and 3 of the Kentucky column, which in an earlier part of this paper have been identified with the Sharon and Mercer horizons of Ohio and Pennsylvania. A well record on the West Virginia side of the river shows the Eagle coal bed at about 100 feet below the Campbells Creek (Warfield) coal bed and 320 feet above the Nuttall (Sharon) sandstone, evidencing a remarkable uniformity of conditions over a great area. The Lower Pottsville is but 378 feet to the first red beds, about one-fourth of the thickness in Fayette county, 60 miles eastward.

Dingess, in Mingo county, of West Virginia, is about 10 miles south of east from Warfield. There Doctor White combined the exposed section with a well record as follows:*

	Feet.	Inches
1. *Coal bed, Stockton*	8	1
2. Sandstone, concealed	140	0
3. *Coal, Winnifrede* (?), seen	1	0
4. Concealed, sandstone	195	0
5. *Coal bed, Cedar Grove* (?)	3	1
6. Massive sandstone	40	0
7. *Coal bed*	0	10
8. Shale, sandstone	100	0
9. *Coal bed, Dingess, Campbells Creek*	4	8
10. Sandstone, 10 feet of shale	71	0
11. *Coal bed*	1	0
12. Shales, 10 feet of sandstone	233	0
13. Sandstone [Sharon]	130	0
14. Shale, blue and white	89	0
15. White sandstone	473	0
16. Black shale	11	0
17. *Coal bed*	6	0
18. Black shale	4	0
19. White sandstone	308	0
20. Black shale	22	0

to the lower carboniferous limestone. The lower Pottsville is 1,043 feet thick, and its section may be compared with that obtained opposite Warfield

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*I. C. White: West Virginia Geol. Survey, vol. i, pp. 277, 280; vol. ii, p. 378.

	Feet
1. Sandstone	130
2. Shale, light and white	81
3. White sandstone	112
4. Shelly slate	55

in all, 378 feet. It is clear that the loss westward is wholly in the lower portion, for this section coincides with the upper portion at Dingess; but there is no trace here of the Dingess section below the upper third of number 15. Doctor White identifies the "Dingess" coal bed with that at Warfield, so that number 11 is the Eagle. The interval below it to the Sharon sandstone decreases almost 100 feet, while that between Campbells Creek and Winnifrede increases almost 100 feet, the interval from Sharon sandstone to Winnifrede remaining practically the same—622 feet at Warfield, 648 feet at Dingess.

The record of a boring in southern Lincoln county about 10 miles northeast from Dingess shows a section of the Lower Pottsville differing in composition though resembling in succession that at Dingess.*

	Feet
1. Sandstone	175
2. Blue shale	107
3. Sandstone	403
4. Shale, sandstone	131
5. Sandstone	182
6. Blue shale	18

in all, 1,016 feet. A trace of the coal bed, number 17 at Dingess, is found in 4 feet of black shale underlying the sandstone number 3. The shales have increased at the expense of the sandstones. The decrease in total thickness from Fayette county to this Lincoln locality, 40 miles westward, is barely 400 feet, less than half as much as in the same distance northwestward along the Kanawha river. The line of abrupt change lies very little west from the line passing through this locality and Dingess, which should extend into Floyd county of Kentucky. This is shown by the record of a boring reported by Mr Campbell from southern Wayne county, about 10 miles northwest from Dingess and 15 miles west from the Lincoln County well: †

	Feet
1. Slate	41
2. *Coal bed*	4
3. Slate and rock	327
4. *Coal bed*	6
5. Slate and sandstone	264

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* I. C. White: West Virginia Geol. Survey, vol. i, p. 280.

† M. R. Campbell: U. S. Geol. Survey folios, Huntingdon, 1900.

	Feet
6. Sandstone	280
7. Slate	86
8. Sandstone	87
9. Slate	5

giving 458 for the Lower Pottsville or Crandall's Rockcastle group. As compared with both Lincoln and Dingess, one finds here the lower portion of the section gone and the succession the same as that at Warfield. The coal bed number 4 may be the Campbells Creek and number 2 the Winnifrede, the intervals being very nearly those required by Doctor White's identifications at Dingess.

At 25 miles west of north from the Wayne locality is the record of a boring near Catlettsburg, Kentucky, reported by Mr. Campbell, which though giving little of detail, is extremely important as affording the means of comparison with other sections in all directions. It is

	Feet
1. Clay	40
2. Sandstone and shale	100
3. Slate and shells	100
4. Sandstone	30
5. Blue slate	150
6. Sandstone [Sharon]	60
7. Shale	40
8. Sandstone	80
9. Shale	35
10. Sandstone	60

to the Lower Carboniferous limestone, giving 275 feet for the Lower Pottsville and 420 feet for the overlying rocks. The especial value of the record is that it shows the whole interval from the Kentucky coal 6 to the Lower Carboniferous limestone to be barely 650 feet, so that in less than half of the thickness of the Lower Pottsville at Nuttallburg, 70 miles south of east, one has here the whole Pottsville and a part of the Allegheny.

Mr Crandall's section at this locality shows Kentucky coal 6 at low-water level, consequently just above number 2 of the record. This, the first coal bed above the Ferriferous limestone, a Kittanning bed, evidently the "Lower Kittanning," is 120 feet above Coal 4, the *Tionesta*, and 50 feet below Coal 7. The interval from Coal 6 to the Sharon sandstone is somewhat more than 380 feet in the record. It is interesting to observe that the Lower Pottsville is still thick, 275 feet at Catlettsburg, whereas at Hanging Rock, only 10 miles farther down the Ohio river, it is not more, possibly less, than 80 feet. At Ashland, Kentucky, a little more than 4 miles northwest from Catlettsburg, Coal 6 distinctly overlies the Ferriferous limestone. The dip to Catlettsburg is about 26 feet per mile. Two miles east from Catlettsburg, at Kenova, West Virginia, Doctor White found a thin bed in the river bank, which, judging from the dip, must be Kentucky coal 7.*

Central City, in Cabell county of West Virginia, is 6 miles eastward from Catlettsburg. The record of a deep well bored there is given by Doctor White

	Feet
1. Clay, etc.	26
2. Shale, sand, lime	94
3. Limestone	7
4. Slate, fireclay veins	98
5. Sand, fine	25
6. Slate	50
7. Sand with gas	30
8. Black slate	10
9. Sand, gray	60
10. Black slate	10
11. Sand, gray	85
12. Slate, white, blue	25
13. Sand, limestone	20
14. Slate	20
15. Black slate	175
16. Gray sand [Sharon]	25
17. Slates with *coal 2 feet*, black, blue	105
18. Sand, gray, black	40
19. Black slate	30

to the first limestone and 35 feet above the great mass of limestone 150 feet thick.†

The limestone, number 3, at 203 feet above the black slate, number 8, shows that the latter is in the place of Kentucky coal 6, for the Kentucky sections along the Ohio and Sandy rivers show that limestone at about 200 feet above the coal. The interval to the Sharon sandstone, number 16, is 395 feet, or practically the same as at Catlettsburg. The Lower Pottsville is 200 feet, or 235 feet thick, if the whole of the black shale to the great limestone is to be included. The double sandstone, numbers 5 and 7, represents the Charleston sandstone. Doctor White states that the "Pittsburg" coal bed is about 340 feet above the mouth of the well, or 670 feet above the black shale, number 8. If this shale

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*M. R. Campbell: Huntingdon folio.
A. R. Crandall: Report on Greenup, etc., sec. 81.
I. C. White: Bull. no. 65, p. 158.

†I. C. White: West Virginia Geol. Survey, vol. i, p. 275; Bull. no. 65, p. 135.

represent the Lower Kittanning of Pennsylvania, the estimated altitude of the Pittsburg is very nearly correct, for in southeastern Ohio the Lower Kittanning is from 134 to 150 feet below the top of the Allegheny, and the Conemaugh is about 500 feet thick, so that bed ought to be about 650 feet below the Pittsburg.

Mr Campbell reports the record of a boring made at Huntingdon, 2 miles northeastward from Central City, which shows

		Feet
1.	Clay	20
2.	Red shales	330
3.	Sandstone	125
4.	Black shale	3
5.	*Coal bed*	10
6.	Shale	30
7.	*Coal bed*	4
8.	Shale	40
9.	*Coal bed*	6
10.	Shale	332
11.	White sandstone	100
12.	Shale	172

The thick sandstone, number 3, is the same with the double sandstone at Central City, as recognized by Doctor White and Mr Campbell, the latter seeing in it his Charleston sandstone, which overlies the Black flint of the Kanawha valley. Numbers 4 to 10, inclusive, are the Kanawha formation, and numbers 11 and 12 are the Lower Pottsville. Number 5 is Kentucky coal 6, the Stockton of the Kanawha valley, or possibly that bed may be represented by numbers 5 and 7, as the Stockton and Lewiston. Number 9 is very nearly in the place of the black shale, number 10, of the Central City well. Doctor White gives a measured section at Huntingdon from the Pittsburg coal bed to the bottom of the sandstone, number 3, showing the interval to be 660 feet, or 10 feet less than the estimated interval at Central City. Sandstone seems to be wholly wanting in the Kanawha at Huntingdon.*

Mr Campbell, in the same folio, gives also the records of two borings in eastern Cabell county, at about 14 miles south-southeast from Huntingdon. The Lower Pottsville in both appears to be a continuous mass of sandstone, 410 to 420 feet thick, showing rapid increase from Huntingdon, with disappearance of the bottom shales. The shale at the bottom of the Kanawha is 275 feet in one well and 339 in the other, above which, in each, is sandstone to a coal bed, 5 to 6 feet thick, at 355 to 360 feet above the Sharon sandstone. A sandstone 160 feet thick overlies the coal bed.

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* M. R. Campbell: Huntingdon folio.
I. C. White: Bulletin no. 65, p. 84.

The record of a boring at Charleston, on the Kanawha, suffices to link the tracing. It is*

		Feet.	Inches
1.	*Coal bed*	3	0
2.	Shales and slates	55	0
3.	*Coal bed*	1	6
4.	Sandstones and shales	116	0
5.	Slaty *coal*	5	0
6.	Shale and sandstone	203	0
7.	Coarse sandstone	70	0
8.	*Coal bed*		
9.	Shales and sandstone	90	0
10.	Shales	30	0
11.	Sandstone	580	0

Number 1 is the Stockton, number 5 the Winnifrede, and number 8 the Campbells creek. Number 3 may be the Lewiston. The great mass of shales observed in so many sections toward the west has become unimportant and the Lower Pottsville shows no shales or coal in the record. The Stockton coal bed is about 800 feet below the Pittsburg coal bed, the increased interval being due chiefly to thickening of the Charleston sandstone and the Upper Conemaugh.

The identity of the Campbell Creek coal bed with that at Warfield, Kentucky, seems to have been placed practically beyond doubt by Doctor White's studies, thus fixing it at the Sharon horizon. A matter of very curious interest is the presence of the lenticular limestones along the Kanawha valley and in a so great area within Kentucky, while they are absent or at least not reported from the intervening space in West Virginia, except in one of Doctor White's sections. The Winnifrede coal bed is evidently equivalent to Kentucky coal 3, the Splint of Warfield, the Peach Orchard and McHenry coals of Kentucky, representing the Mercer horizon of Pennsylvania and Ohio. The Stockton is distinctly equivalent to Kentucky coal 6, which is at a little distance above the Ferriferous limestone, and therefore the Lower Kittanning of Pennsylvania; but the Stockton may embrace a higher bed and represent the whole Kittanning horizon. This reference bears out the suggestion made by Doctor White that the Stockton might prove to be Lower Kittanning and not Upper Freeport, as has been the belief for almost one-third of a century. The relation of the Coalburg is not wholly clear. To the writer it appears to be most nearly at the horizon of Kentucky coal 4, the Tionesta of Ohio and Pennsylvania, and so the highest bed of the Pottsville.

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*I. C. White: Bulletin no. 65, pp. 58, 136, 195.

WEST VIRGINIA, NORTH FROM THE KANAWHA RIVER AND CHESAPEAKE AND OHIO RAILROAD

The effort now will be to trace the section through the northern part of West Virginia. In this extensive area the sole reliance must be the work of I. C. White, who has published the records of oil borings in the central portions of the region and has supplemented them by many carefully measured sections along the outcrops. His studies make available also the scattered observations by other students, which will be acknowledged in the proper places. To trace the section is comparatively simple in the eastern part of the area, where the well records have been checked by measured sections, but in the central part of the area, where one is dependent solely on well records, the work becomes excessively difficult. The absence of limestones, the almost total disappearance of the coal beds, and the abrupt variations in sandstones, elsewhere persistent, render wholly impossible the tracing of minor horizons, and at times even the boundaries of the formations become obscure. The section will be followed northward and northeastward from the Kanawha river to Pennsylvania through the easterly counties of the area; afterward, by means of oil-well records, southwardly through the western counties to the Kanawha, there to connect with the work already reviewed. The complexity of the problem is the excuse for the detail in which it is considered.

Major W. N. Page's carefully measured section at Ansted, 5 miles north from the Kanawha river, in Fayette county, gives 1,051 feet as the thickness of the Kanawha formation and 490 feet as the thickness of the Sewell formation, resting on 60 feet of the Raleigh. The intervals between the coal beds, as named by Doctor White, are

	Feet.	Feet
Stockton		
Interval	50	
Lewiston (?)		50
Interval	137	
Coalburg		190
Interval with thin coal	79	
Winnifrede		218
Interval	229	
Cedar Grove (?)		512
Interval	108	
Campbells Creek		620
Interval	93	
Eagle		724
Interval	305	
Nuttall sandstone		

The numbers opposite the coal beds indicate the distance below the Stockton coal bed. The Black flint is present in the section, but it disappears very quickly northward. The Charleston sandstone with its two coal beds, the number 5 Block and the Mason, is persistent, and its massive cliffs make simple the carrying of the Stockton horizon. Sandstones, many of them massive, appear in the section above the Campbells Creek coal bed, and farther north are as interesting as the coal beds themselves.

At Gilboa, in southern Nicholas county, 10 miles northeast from Ansted, Doctor White's section shows the massive Charleston sandstone, with the blossom of the Stockton coal under it; the Black flint has disappeared already along this line, but it is present under the sandstone at only 2 miles toward the west. The thickness of the Kanawha has decreased within 10 miles from 1,051 to 688 feet; evidence of coal was seen at 70, 130, 160, 250, 340, and 545 feet below the Stockton. The lowest bed is the Campbells Creek; no other is exposed except that at 340 feet, which is evidently at the horizon of one of the thin beds occasionally seen on the Kanawha in the interval between the Cedar Grove and Winnifrede. The exposures throughout are poor, but massive sandstones are present under the Stockton as well as under the beds at 160 and 340 feet. The decrease in the thickness is due almost wholly to loss of the lower members, for here the Campbells Creek coal bed is only 120 feet above the Nuttall, whereas at Ansted the interval is 400 feet.

On Powell mountain, about 15 miles due north from Gilboa, the section extends from the top of the Charleston sandstone to about 330 feet below the Stockton. The Mason and number 5 Block coals of the Charleston sandstone, as well as the Stockton, are well exposed, and coal beds were seen at 50, 140, 193, 223, 254, and 271 feet below the Stockton, all of them thin. There is much sandstone below the Stockton, but the exposures are imperfect. The Campbells Creek coal bed is not reached here, but it is shown in Muddlety creek, 4 or 5 miles away, at somewhat more than 550 feet below the Stockton.

Cottle knob, about 11 miles east from Powell mountain, in southwest Webster county, is capped by the Charleston sandstone. The Stockton is not exposed, but coal beds were seen at 255, 588, and 604 feet below the lowest exposure of sandstone. The Kanawha is probably 700 feet thick here. The second and third beds are splits of the Campbells creek. Three miles farther east, at Camden-on-Gauley, 30 miles northeast from Ansted, a well record, beginning about 250 feet below the bottom of the Kanawha, shows that the Lower Pottsville is not more than 950 feet thick. The Raleigh sandstone is 92 feet; the Sewell (Sewanee), Quinnemont, and some others of the southern coal horizons are recognizable, but of the section below the Raleigh sandstone only 416 feet remain. The decrease as compared with Nuttallburg is due largely to loss of the lower part of the section.

Near Weeses station, about 10 miles east of north from Cottle knob, the section shows coals at 100, 385, 455–482, and 585 feet below the Stockton. The extremely thin coal at 100 feet is between massive sandstone, 90 and 110 feet, beginning at 10 feet below the Stockton. The bed at 455–482 feet is the divided Campbells Creek, and that at 585 feet is the Eagle, at 25 feet above the Nuttall sandstone, which forms cliffs along the Laurel fork of Elk river 75 to 100 feet high. Respecting the identification of the Campbells coal bed no doubt exists, as it can be followed continuously along the Gauley river from the Kanawha to within 4 or 5 miles of this locality, where the Kanawha is but 617 feet thick. The upper part of the section is followed easily down Laurel fork to the mouth, and thence up the Middle fork on which, at about 4 miles east from Weeses station, Doctor White's section shows the massive sandstone beginning at 30 feet below the Stockton and exposed for 150 feet, below which exposures are poor to the Campbells Creek coal bed, at 460 feet below the Stockton; the Eagle is at 560 feet, or 40 feet above the Nuttall. The exposure is imperfect, and whether or not the Campbell's Creek is double as at the last two localities can not be determined. The thickness of the Kanawha is 607 feet, a decrease of not more than 75 feet in 35 miles, from Gilboa on the Fayette-Nicholas border. At this place the Lower Pottsville is 700 feet thick, mostly conglomerates, with several thin coal beds. It has lost 250 feet in 14 miles from Camden-on-Gauley.

On the north fork of Elk river the Charleston sandstone is conspicuous from the mouth of Middle fork. At 2 miles below Hacker, about 10 miles north-northeast from Weeses station, coal beds are shown at 120, 230, 415, and 520 feet below the Stockton, the last at 30 feet above the Sharon sandstone, the thickness of Kanawha being 561 feet. The third bed is the Campbells Creek and the fourth the Eagle. The decrease in thickness is above the Campbells Creek. There is much sandstone in the 120 feet interval below the Stockton, and the 6-inch coal bed may be the same with that at 100 feet near Weeses station.

In southern Randolph county, near Pickens, on the Buckhannon river, 10 miles east from Hackers and 16 miles northeast from the section on Middle fork of Elk river, the Kanawha is 582 feet thick. The massive sandstone is present under the Stockton, with a double coal in it at 150 feet down. The coal beds in the section are at 150, 452–479, and 569 feet below the Stockton; the double bed at 452–479 represents the Campbells Creek, and the lower division, 3 feet thick, is known locally as the Pickens coal bed. That at 569, known locally as the "Gimmel," is most probably the Eagle coal bed.

No measurements have been published for localities between Pickens and the northern border of Randolph county, almost 20 miles. Some borings at about 15 miles north from Pickens indicate a thickness of not far from 500 feet for the Lower Pottsville. At the bottom, for nearly 200 feet, the rocks are almost wholly conglomerates or coarse sandstones. Some coal beds are present higher up, but they are very thin and apparently do not occur at the same levels in the different borings, which are separated by short distances.

Borings were drilled with diamond drill in northern Randolph county at two places on the Valley river. These are reported by Doctor White in connection with the exposed section to the Stockton coal bed. The first north from Beaver Creek is

		Feet.	Inches
1.	[*Stockton*] *coal bed* and partings	14	0
2.	Fireclay and sandy shales	10	0
3.	Sandstone, conglomerate with five layers of shale or clay; in all, 9 feet 1 inch	282	0
4.	*Coal bed*	0	4
5.	Shale	13	0
6.	Sandstone and sandy shale	48	5
7.	Shale and black shale	6	4
8.	Sandstone and sandy shale	36	1
9.	*Coal bed,* including 12 feet of sandy slate	15	1
10.	Fireclay and sandstone	5	8

to bottom of boring, 431 feet 3 inches. The exposure below the Stockton coal is complete, and the sandstone shows no break for 187 feet. It contains streaks as well as three beds of conglomerate, 15, 26, and 10 feet thick. The upper portion of the mass, 50 to 75 feet thick, is the Roaring Creek sandstone of I. C. White, so named from Roaring creek, in Randolph county, where it forms a fall of 50 feet or more. The mass can be followed up the Valley river to Pickens, in the southern part of the county, where it forms cliffs on the hillsides. The coals in this section are at 292 and 396 to 411 feet below the Stockton. The other boring was opposite the mouth of Laurel run, near the Randolph-Barbour line. It differs somewhat:

		Feet.	Inches
1.	[*Stockton*] *coal bed* and partings	10	0
2.	Interval	293	10
3.	*Coal bed*	1	2
4.	Sandstone and sandy shale	54	5
5.	Black shale	8	9
6.	Sandstone and sandy shale	31	9
7.	Sandstone	141	11
8.	*Coal bed,* divided by 7 feet 11 inches of shale	10	9
9.	Fireclay and sandstone	62	9

in all, 615 feet; but before discussing further the relations of these beds it will be wise to take up another line, beginning at Charleston, in the Kanawha, and meeting at Philippi, in central Barbour, the one followed thus far.*

Doctor White has given a practically complete section at Charleston, extending from the Pittsburg coal bed to the Lower Carboniferous. The portion below the Stockton coal has been quoted already; it is necessary only to give the portion above, and then to summarize the whole. Condensed, it is

		Feet
1.	*Pittsburg coal bed*	
2.	Interval	350
3.	Red shales with Ames limestone	50
4.	Interval	176
5.	Massive and pebbly sandstone	75
6.	*Mason coal bed*	2
7.	Shale	10
8.	Sandstone	120
9.	Shales	10
10.	Black flint	5
11.	Shales	2
12.	*Stockton coal bed*	

The interval from the Pittsburg to the sandstone, number 5, is 566 feet, and to the Mason coal bed 651 feet. Numbers 5 to 8 are the Charleston sandstone of Campbell, here very much thicker than at Huntingdon, The interval between the Mason and Stockton is 147 feet in this section. but at a little way farther up the Kanawha it is somewhat greater. The number 5 Block coal bed is from 40 to 65 feet above the Stockton, and usually a thin coal bed rests on the Flint. If Doctor White's suggestion be accepted and the Mason be taken as the Upper Freeport of Pennsylvania, the division of the column would be

	Feet
Pittsburg coal bed	
Conemaugh	651
Allegheny	200
Pottsville	1,100

The subdivision is only approximate for Allegheny and Pottsville, but it may be taken tentatively for the study. In tracing the section the Stockton will be used as the key-bed. At Charleston the thickness from Stockton to Lower Carboniferous is about 1,150 feet, almost equally divided between Kanawha and Lower Pottsville. The Campbells Creek coal bed is 450 feet below the Stockton and 120 feet above the Nuttall (Sharon) sandstone.

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* I. C. White: West Virginia, vol. ii, pp. 360-362, 363, 364-365, 365-366, 366-367, 368, 369, 459-460, 534-535, 616, 623.

The Black flint comes up from the bed of Elk river at Queens shoals, 20 miles northeast from Charleston, and on the border of Kanawha and Clay counties, with the Upper Freeport (Mason) coal bed at 175 feet and the number 5 Block (Mahoning) coal bed at 80 feet above it. Doctor White's section at Clay court-house, 12 miles farther northeast, shows*

	Feet
Stockton coal bed	3
Massive sandstone and concealed	100
Coalburg coal bed	6
Sandstone and concealed	15

The Coalburg bed, between two massive sandstones, is mined at Clay, where it is largely splint, as on the Kanawha, and contains the characteristic "niggerhead" slate. The Stockton is thin and slaty here, but in most of this region it is very thick and broken into numerous benches by variable partings.

Ten miles northeast, at one and a half miles below Sutton, in Braxton county, a well record is*

		Feet
1.	Conductor	50
2.	Blue slate	30
3.	Sandstone	80
4.	*Coal bed*	6
5.	White sandstone	230
6.	Black slate	50
7.	Gray sandstone	100
8.	Black slate	20
9.	Brown limestone	75
10.	Black slate	30
11.	Gray sandstone	50
12.	Black slate	75
13.	Gray sandstone	20
14.	White limestone	50
15.	Black slate	40
16.	Sandstone	50
17.	Blue slate	60
18.	Gray limestone	55
19.	Blue slate	54
20.	Yellow sandstone	25
21.	Shale	40
22.	Sandstone	210
23.	Slate	30

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*I. C. White: West Virginia, vol. ii, pp. 239, 456.

The coal bed, number 4, is the Stockton, as the boring begins in the Charleston sandstone, which here is 250 feet thick. The great mass of sandstone underlying the coal is the same with that observed in Webster, Nicholas, and Randolph counties. The underlying coal beds of other sections have disappeared or are represented by carbonaceous matter distributed through black shale at 230, 380, 475, 555, and 700 feet below the Stockton, no one of which, except that at 475, can be correlated with any bed at Charleston. In view of the thickening of the measures, it is quite possible that that shale may represent the Campbells Creek horizon. It is very near the place of that coal bed, on the middle fork of Elk, 15 miles southeast, in Webster county. The distance from Stockton to Lower Carboniferous is 1,264 feet, about 200 feet greater than at Charleston, more nearly that to be expected on the Kanawha, at 7 or 8 miles above Charleston.

Where the Stockton coal bed comes today at 2½ miles above Sutton, the interval to the first coal is 152 feet 6 inches, very largely concealed, but containing some massive sandstone. A second coal bed, also a double bed, is at 15 feet lower, the intervals being 155 and 175 feet. At 3 miles east-northeast from Sutton these beds are shown again and somewhat thinner. Massive sandstone is present below the Stockton, as well as below the lowest bed, the lower division of the sandstone being exposed for 40 feet or to 240 feet below the Stockton. The Upper Freeport (Mason) coal bed is present at the latter locality, 135 feet above the Stockton.*

Near Wildcat, in the southern panhandle of Lewis county and 10 miles northeast from the last, Doctor White obtained a measurement of the Kanawha. Here one is about 8 miles north from the Hacker locality in northern Webster. The section is †

	Feet.	Inches.	Feet
1. [*Stockton*] *coal bed*	12	9	
2. Sandstone and concealed	125	0	
3. *Coal bed*	Blossom		
4. Concealed	80	0	
5. *Coal bed*	Blossom		
6. Concealed and sandstone	175	0	
7. *Coal bed*	Blossom		
8. Sandstone	20	0	
9. Shale and concealed	25	0	
10. Interval	30	0	
11. *Coal bed*	7	0	to 10
12. Interval	25	0	

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*I. C. White: West Virginia, vol. i, p. 270; vol. ii, pp. 453, 454.

†I. C. White: Vol. ii, p. 364.

making a thickness of 502 feet 9 inches. The coal beds are at 125, 205, 380, and 470 feet below the Stockton.

At Hackers, on Holly, 8 miles south, the coals are at 120, 230, 415, and 520 feet, and the thickness of the Kanawha is 561 feet. At Pickens, in Randolph county, 12 miles east from the Holly River locality, the coals are at 150, 451 to 478, and 568 feet, and the thickness is 581 feet.

It is apparent that the variations in thickness are largely above the Campbells Creek bed, which is at 380, 415, and 451 to 478 feet below the Stockton at the several localities. The lowest coal of the Wildcat section is equivalent to the Gimmel of Randolph, which is very clearly at the Eagle horizon. The total thickness from Stockton to the Lower Carboniferous is not far from 1,000 feet, so that the section is almost as thick as at Charleston, but a change appears abruptly at a little distance west and northwest from this line.

A section obtained near Ireland,* 4 miles north from Wildcat, affords means for checking up the tracing; for there the interval from the Pittsburg to the Stockton is 721 feet, with coal beds at 21 and 105 feet above the latter. The upper bed, the Upper Freeport, is 613 feet below the Pittsburg and rests on 84 feet of massive sandstone.

Passing over into Upshur county to the Buckhannon river, one comes to Alexander, 10 miles north from Pickens. The Stockton coal bed is mined at many places along the river below Pickens, while the Charleston and Roaring Creek sandstones are in cliffs. The section is clear up the little Kanawha river from Wildcat to within 2 miles of the Buckhannon, and it is repeated on the other side of the divide. At Alexander the section is †

	Feet.	Inches
1. Massive pebbly sandstone	60	0
2. Concealed	5	0
3. [*Stockton*] *coal bed* and partings	13	4
4. Concealed	10	0
5. Massive pebbly sandstone	60	0
6. Shale	5	0
7. *Coal bed*, seen	2	0
8. Concealed and sandstone to river	200	0

Here is the great sandstone underlying the Stockton, with a coal bed in it at 75 feet, the upper portion or Roaring Creek sandstone being separated from the lower. The Stockton coal bed passes under the river at Sago, 5 miles south from the village of Buckhannon, but comes up again at the Upshur-Barbour line, where one is at 12 miles west-northwest from the borings already recorded on the Randolph-Barbour border.

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*Op. cit., p. 239.

I. C. White: Vol. ii, p. 445.

But before returning to consideration of those records, a record should be given which was obtained on the Upshur-Lewis border, about 6 miles west from Buckhannon and about 15 miles north from Wildcat, for this illustrates the great change which has taken place between southern Upshur and the line of Buckhannon. The measurements are reported by Doctor White upon the authority of Mr F. H. Oliphant.*

			Feet
1.	*Pittsburg coal bed*		
2.	Interval		225
3.	Red rock, soft		125
4.	Shales		325
5.	Sandstone	30	80
	Slate and shell	20	
	Sandstone	30	
6.	[*Stockton*] *coal bed*		12
7.	Sandstone	20	73
	Slate	13	
	Sandstone	30	
	Slate	5	
	Sandstone	5	
8.	*Coal bed*		5
9.	Sandstone		95
10.	Shales		68
11.	Sandstone		15
12.	Limestone, pale brown		17
13.	Pebbly sandstone		20
14.	Black slate		10
15.	Sandstone, gray, hard		45
16.	Black slate and blue "limestone"		75
17.	Sandstone, gray, hard		50
18.	Limestone		10
19.	Sandstone, white, yellow, hard		150

to the Lower Carboniferous red shale. The interval from Pittsburg to Stockton is 755 feet, if the distance of the Pittsburg above the well curb was given accurately; this is about 30 feet more than in southern Lewis. The interval from the Stockton coal bed to Lower Carboniferous is 630 feet. On the Upshur-Randolph border, 10 miles southeast from Buckhannon, the Lower Pottsville is approximately 500 feet thick, while here, only 15 miles away toward the northwest, the total thickness of Kanawha and Lower Pottsville is less than 650 feet. The coal bed within the great sandstone mass is evidently the same with that seen at Alexander. No trace remains of lower beds except the black slate at about 300 feet below the Stockton, which may represent the Campbells Creek. The coal bed, number 8, has been seen in other sections farther south, and it is shown

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I. C. White: West Virginia, vol. i, p. 255; vol. ii, p. 443.

on the Buckhannon river 3½ miles below Sago, where it is double and 5 feet thick. The Roaring Creek sandstone above it is shown for 50 feet, beginning at 10 feet below the Stockton.

Returning now to northern Randolph, near the Barbour line, 12 miles southeast from the reappearance of the Stockton on the Buckhannon river and a little more than 20 miles east from the well in Lewis county, one finds the Roaring Creek sandstone beginning at 10 feet below the Stockton coal bed and continuing for 282 feet, the coals in the respective borings being at

292 and 395 to 408 feet, with black shale at 354 feet.
292 and 538 feet, with black shale at 350 feet.

The coal at 395 to 408 feet in the southerly boring is absent in the other, as the great sandstone, 141 feet, begins at 400 feet. It is unfortunate that no boring in this immediate region has been carried down to the Lower Carboniferous, as the great change in thickness and type of the Pottsville rocks takes place here. Only 8 or 9 miles southwest the Lower Pottsville is between 400 and 500 feet. On Rich mountain it has been called the Pickens sandstone by Taft and Brooks, who give the thickness as from 400 to 500 feet, increasing southwardly. It is

Light gray or white sandstone.
Brown sandstone shales and coal beds.
Massive gray to white sandstone to conglomerate.*

The lowest division is about 100 feet. The principal coal bed is 3 to 5 feet thick, and at only a little way above the third or lowest portion.

Stevenson describes the Lower Pottsville of Rich mountain along the Staunton pike as a coarse sandstone, with pebbles at times 2 inches in diameter, with micaceous sandstone. In the lower portion quartz crystals occur in great numbers, some of them three-fourths of an inch long and doubly terminated. A coal bed about 3 feet was seen at several localities. The thickness of the mass on the Staunton pike, by barometer, was found to be about 600 feet.†

Passing northward into Barbour county, one finds the great sandstone underlying the Stockton coal bed distinct along the Valley river to within 3 or 4 miles of Philippi, as well as along Buckhannon river to its junction with the Valley river, 4 miles south from that village. The sandstone has been in view all the way down the Valley river from Pickens. At Philippi, 12 or 13 miles north from the Randolph line, a well was bored, the record of which is reported by Doctor White. The

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*J. A. Taft and A. H. Brooks: U. S. Geol. Survey folios, Buckhannon, 1896.

†J. J. Stevenson: Notes on Geology of West Virginia, vol. ii. Proc. Amer. Phil. Soc., vol. xiv, 1875, p. 388.

Upper Freeport (Mason) and number 5 Block coal beds are present at 40 and 115 feet above the Stockton, below which the succession is*

		Feet
1.	[*Stockton*] *coal bed*	
2.	Shale	20
3.	Hard sandstone	45
4.	*Coal bed*	7
5.	Very hard sandstone	30
6.	Shales	40
7.	Hard sandstone	60
8.	Shale, limestone (?)	30
9.	Hard sandstone	25
10.	Shales, limestone (?), 8 feet	113
11.	Hard sandstone	50
12.	Slate and shells	40
13.	Hard sandstone	20
14.	Shales, limestone (?)	28
15.	Hard sandstone	14
	Total	522

to the Mauch Chunk red rock. Here one finds the coal bed under the Roaring Creek sandstone number 3, as at Wildcat, in the Lewis County well and near Sago. The great mass, 280 feet thick in southern Barbour and northern Randolph, is here 237 feet, though no longer continuous, and rests on 113 feet of shales—in all, 370 feet—to number 11, the top of the Lower Pottsville. The coal bed at 395 feet in the Randolph boring is at the place of the Campbell Creek coal bed, and that bed should be in number 10, below the middle. The relations are made thoroughly clear in another boring at about 4 miles northwest from Philippi, where the measurement from the Pittsburg coal bed downward is complete. The interval from the Pittsburg to the Stockton coal bed is 717 feet, with the Ames limestone at 305 feet and the Upper Freeport (Mason) coal bed at 607 feet. The section is important.*

		Feet
1.	[*Stockton*] *coal bed*	
2.	Sandstone, limestone	15
3.	White slate	30
4.	Black slate	5
5.	White slate	30
6.	White sandstone	52
7.	White shale	25
8.	Limestone	10
9.	*Coal bed*	5
10.	Sandstone	15

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*I. C. White: West Virginia, vol. ii, pp. 34, 238, 357, 358, 359.

	Feet
11. *Coal bed*	5
12. Sandstone, pebbly below	56
13. Brown shale	24
14. *Coal bed*	2
15. White shale	18
16. *Coal bed*	2
17. White shale	13
18. Sandstone	40
19. Black shale	35
20. *Coal bed*	3
21. Shale, brown, black	43
22. Sandstone	25
23. Black shale	10
24. Sandstone	55
25. Shale, mostly black	45

in all, 538 feet to the Lower Carboniferous. The Roaring Creek sandstone seems to have disappeared, and the black slate at 45 feet below the Stockton is apparently the coal bed number 4 of the last section. The mass of sandstone below that coal bed is no longer continuous, and coal beds are present at 142, 162, 247, 267, and 357 feet below the Stockton. The Campbells Creek bed is that at 357 feet. It is very clear that the great Lower Pottsville of the Kanawha region and southward has almost disappeared. In this record there remain only 135, in the other only 152 feet, to represent the 1,400 feet at Nuttallburg. Numbers 6 to the bottom are the Pottsville of western Pennsylvania, which may be divided thus:

Number 6 is the Homewood sandstone.
Numbers 9 and 11 are in the *Mercer* coal group.
Number 12 is the Upper Connoquenessing sandstone.
Numbers 14 and 16 are in the Quakertown shales.
Number 18 is the Lower Connoquenessing sandstone.
Number 20, the *Campbells Creek coal bed,* is the *Sharon coal bed.*
Number 22 is the Sharon sandstone.

Descending the Valley river, one comes to Moatsville, on the border of Taylor county, where the Stockton coal bed is at 10 feet above a massive pebbly sandstone; and at Webster, in Taylor county, about 5 miles west from Moatsville, the section is*

	Feet.	Inches
1. *Pittsburg coal bed*		
2. Interval	308	0
3. Ames limestone	1	0
4. Shales	193	0

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* I. C. White: Vol. ii, pp. 232, 297, 356.

	Feet.	Inches
5. *Coal bed*	0	9
6. Interval	120	0
7. [*Upper Freeport*] *coal bed*	3	0
8. Clay, shale, limestone, sandstone	52	0
9. *Coal bed*	4	9
10. Shale, limestone	44	0
11. [*Stockton*] *coal bed*	5	10
12. Clay, limestone, shale	10	0
13. Sandstone and conglomerate	172	0
14. Very hard conglomerate	47	0

Here the Stockton coal bed is 728 feet below the Pittsburg coal bed. Traces of coal were found at 75 and 180 feet below the Stockton; that at 180 feet answers to the bed at 142 in the boring northwest from Philippi, for the interval to the first coal below has increased 35 feet. The horizon of the Campbells Creek coal is not reached, as it lies beneath the great sandstone.

Not far from the line of Webster the section changes, and a new series of coal beds comes in between the sandstone overlying the Stockton and the Pottsville, for at Valley Falls, 6 or 8 miles north from Webster, several coal beds are shown, which are practically continuous thence to the Pennsylvania line. A complete section at Morgantown, about 8 miles from the state line, is given by Doctor White. From the Pittsburg coal bed to the Upper Freeport coal is exposed; from that below to the Pottsville sandstone was obtained by measuring a diamond-drill core; the Pottsville is exposed.* The Conemaugh is much thinner here.

	Feet.	Inches
1. *Pittsburg coal bed*		
2. Interval	285	0
3. Ames limestone	1	6
4. Interval	164	0
5. Mahoning sandstone	100	0
6. Shales	40	0
7. *Upper Freeport coal bed*	5	7
8. Fireclay	7	7
9. Sandstone	53	2
10. *Coal bed*		
11. Shales and fireclay	22	8
12. Sandstone and fireclay	7	7
13. Black shale and sandstone streaks	15	4
14. *Upper Kittanning coal bed*	2	10½
15. Shale and fireclay	32	6½
16. *Middle* and *Lower Kittanning coal bed* with black shale.	8	0½
17. Fireclay and sandstone streaks	14	11½

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*I. C. White: Vol. ii, pp. 230, 346.

	Feet.	Inches
18. Sandstone, shale streaks in upper part	54	2
19. Shale	2	4
20. *Clarion coal bed*	1	6½
21. Fireclay	11	6½
22. Interval, about	10	0
23. Pottsville sandstone, about	250	0

The interval between the Upper Freeport coal bed and the Stockton horizon is practically the same as at Webster, but here the Stockton is represented by numbers 14 to 16, in all occupying a space of 43 feet 6 inches, while from the bottom of 16 to the Clarion coal bed is 71 feet 6 inches, the Roaring Creek sandstone being number 18. Below the Clarion coal bed is the great sandstone mass overlying the Campbells Creek or Sharon coal bed. No detailed measurement is given of this mass for the gorge through Chestnut hill east from Morgantown, but the section in Cheat River gorge, 6 or 7 miles farther north, shows a coal bed within the sandstone and the Campbells Creek underlying, while the Sharon sandstone and the rest of the Lower Pottsville of the southern localities have disappeared, permitting the shales below the Connoquenessing sandstone to be continuous with the Shenango shales of the Lower Carboniferous.

A brief reference only can be made to the region lying east from the area already studied, as the information at present available is very small.

Some insignificant areas of Pottsville have escaped erosion on the mountains forming the boundary between Tucker and Randolph counties at the west and Grant and Pendleton at the east. Mr Darton states that his Blackwater formation, which is equivalent to the Pottsville, consists of*

	Feet
1. White conglomerate	100
2. Sandstone, shales, *coal* beds	200
3. Gray sandstones	100

These outlying patches are almost on the strike with the most southeasterly extension in Mercer and Tazewell counties, south from the Kanawha-New river.

Messrs Darton and Taft state that in the Potomac field of Tucker, Grant, and Mineral counties the thickness of the Blackwater varies from 645 feet in Tucker to 290 feet on the Potomac.†

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*N. H. Darton: U. S. Geol. Survey folios, Franklin, 1896.

†N. H. Darton and J. A. Taft: U. S. Geol. Survey folios, Piedmont, 1896.

Mr David White obtained in Blackwater gorge, Tucker county, an important section, which, reduced from the diagram, is as follows:

	Feet.	Inches
1. Sandstone	15	0
2. Massive conglomerate	40	0
3. Soft sandstone, with lenses of shale containing fossil plants	25	0
4. Massive conglomerate	40	0
5. Soft sandstone, lenses of *coal* and shale with fossil plants, Mercer forms	20	0
6. Soft sandstone	63	0
7. Shale	10	0
8. Dark shale	5	0
9. Shale with nodular iron ore	5	0
10. Sandstone	10	0
11. *Coal* and fireclay	Thin.	
12. Clay shales, with plants and nodular ore	25	0
13. *Coal bed*	Thin.	
14. Green shale and blue clay	20	0
15. Sandstone	40	0
16. Shaly sandstone	10	0
17. Sandstone and conglomerate	45	0
18. Shaly sandstone	28	0
19. *Coal*, clay, carbonaceous shale	10	0
20. Shales, lower portion *coaly*	20	0
21. *Coal bed*	1	6
22. Shale	15	0
23. Sandstone	25	0

to the Lower Carboniferous red shale. Number 1 is at 10 feet below a thin coal bed associated with shales containing plant remains of Allegheny type.

Numbers 6 to 10 appear to represent the Connoquenessing sandstones, with the Quakertown shales, and number 15 is evidently the Sharon sandstone, the Lower Pottsville being represented by numbers 15 to 23, inclusive, thus giving for the Upper Pottsville a thickness of 278 feet and for the Lower Pottsville of about 195 feet.

WEST VIRGINIA—CENTRAL AND WESTERN COUNTIES

Passing now to the western counties of West Virginia, the effort will be to follow the section westward to the Ohio river and southward to the Kanawha. At Morgantown the intervals from the Pittsburg coal bed are

	Feet
Upper Freeport coal bed	560
Kittanning coal bed	670
Roaring Creek sandstone	713
Top of Pottsville	800

The intervals are smaller than at the south or north, owing to thinning of the Conemaugh and, to a less extent, of the Allegheny.

At the Brown well, 10 miles northwest from Morgantown, on the Pennsylvania line, the intervals are 570, 670, 745, 820 feet, with 35 feet between the Roaring Creek and the Pottsville. This formation shows

	Feet
1. Sandstone	20
2. *Coal bed*	2
3. Slate	8
4. Sandstone	180
5. "Slate and shells"	20

in all, 230 feet, separated by 140 feet of mostly red rock from the Lower Carboniferous limestone; but in a neighboring well the top sandstone is 43 feet and the overlying shale but 7 feet. Number 1 is evidently the "Homewood" and number 4 the "Connoquenessing." At about 10 miles southwest from the Brown well and 2 miles northeast from Fairview, in Marion county, the Pottsville is reached at 826 feet below the "Pittsburg," and consists of two sandstone plates, 50 and 136 feet respectively, separated by 69 feet of "slate and shells," so that the upper part of the Connoquenessing has been replaced by shale. The lower plate rests on red rock, and is 165 feet above the limestone. At about 8 miles west from Fairview the change is more marked. There the Upper Freeport is at 578, but below it only "slate and shells" is recorded to 918 feet, where a sandstone 80 feet thick is reached. This rock, 240 feet above the limestone, represents the middle portion of the Connoquenessing mass at Browns. The same condition exists at Metz, 5 miles southwest from the last, where the sandstone, 75 feet thick at 918 feet, rests on 245 feet of unrecorded material. In northeastern Wetzel, at Hundred, 9 miles northwest from Metz, 100 feet of sandstone appear at 930 feet, with apparently only shales up to the Roaring Creek sandstone. Near Cogley, 10 or 12 miles farther north in Marshall county, the change is complete, for the Roaring Creek sandstone is at 705 feet, and the next sandstone, the Logan, is at 1,095 feet. At 10 miles north from Cogley, in the same county, the normal condition begins to reappear, for beginning at 770 feet below the Pittsburg, one has

	Feet
1. Sandstone	10
2. Slate	60
3. Sandstone	20
4. Slate	50
5. White sandstone	85
6. Black sand and slate	110

to the limestone, which here is but 1,065 feet below the Pittsburg coal bed. The shale is still present in abnormal proportion. It is not possible to determine how much of number 6 belongs to the Pottsville, as no details are given in the record. Five miles farther west, in the same county, at Moundsville, on the Ohio river, one finds, beginning at 780 feet

	Feet
1. Sand	10
2. *Coal bed*	3
3. Sand	10
4. Black slate and shells	31
5. Sand	67
6. Slate and shells	82

to the limestone, which is only 983 feet below the Pittsburg, as against 1,170 feet in the Brown well. At Wheeling, on the Ohio river, and about 12 miles north from Moundsville, one finds a condition similar to that already observed at several localities in southwestern Pennsylvania, for a sandstone begins in one well at 564 feet below the Pittsburg, in another at 534, which is continuous with the Logan sandstone. In one of the wells it is broken by the Stockton (Kittanning) coal bed at 96 feet below the Upper Freeport. Doctor White finds no difficulty in differentiating the Pottsville in this well, for at 112 feet below the Kittanning the section is

	Feet
1. White sandstone	70
2. Yellowish gray sandstone	50
3. Yellowish gray coarse sandstone	170

resting on the brown coarse sandstone of the Logan. The contrasts are sharp in this well, yet in the other well, 3 miles south, where the sandstone is 706 feet thick, the portion assigned to the Pottsville is wholly fine grained and white, as indeed is most of the Logan—an excellent illustration of the variability of the deposits.

At Wellsburg, in Brooke county, 15 miles north from Wheeling, the Pottsville, beginning at 738 feet below the Pittsburg, shows

	Feet
1. Sandstone	15
2. Slate	75
3. Sandstone	145
4. *Coal bed*	6
5. Slate	31

or 272 feet to the Logan sandstone, which is 1,035 feet. The coal bed is at the Sharon horizon, number 3 being clearly the Connoquenessing. At 15 or 16 miles farther north, near New Cumberland, the section is

	Feet
1. Sandstone	15
2. Slate	30
3. Sandstone	110
4. Slate	45
5. Sandstone	25
6. Slate	35

to the Logan sandstone. Here one is at the extreme point of the "Panhandle," 2 miles west from line of Beaver county, Pennsylvania, and at about the same distance from the northern part of Jefferson county, Ohio. It is very possible that number 5 represents the Sharon sandstone, for the southern limit of that bed is not far north from this latitude in western Pennsylvania. The well at McDonalds, in Washington county, Pennsylvania, is about 15 miles east-northeast from Wellsburg. Its record shows little aside from shale for 886 feet below the Pittsburg coal bed. The Pottsville is 256 feet thick, including 58 feet of black shale resting on the Logan, which is 1,142 feet below the Pittsburg, an increase of 107 feet in 15 miles, due wholly to increase in the Conemaugh and Allegheny, the Pottsville having decreased 16 feet in the interval. In the same way one explains the small intervals in West Virginia near the Pennsylvania line. At McDonalds and Morgantown the intervals are, to the

	Feet.	Feet
Upper Freeport coal bed	613	560
Upper Kittanning coal bed	749	670
Top of Pottsville	886	800

showing a decrease southward of 53 feet in the Conemaugh and of 45 feet in the Allegheny. The loss is regained farther south.*

Returning to the southeasterly side, one finds at Fairview, in Marion county, about 20 miles south of west from Morgantown, the top of the Pottsville at 808 feet below the Pittsburg. The section is

	Feet
1. Sandstone	60
2. Slate and shells	60
3. Limestone (?)	20
4. Sandstone	100
5. Slate	30

in all, 270 feet, separated by 165 feet of mostly red rock from the limestone, thus differing little from the section at 2 miles northeast, except in thickening of the shales, numbers 2 and 3, at the expense of number

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*I. C. White: West Virginia Geological Survey, vol. i, pp. 218, 234, 238, 239, 247, 348, 349, 350, 363, 365, 366, 369. Doctor White must not be held responsible for the limits assigned to the formations. The writer has taken the records as reported by Doctor White and has drawn the lines himself.

4. At Mannington, also in Marion county and 8 miles southwest from Fairview, one has A. J. Montgomery's record of the well drilled by him for Doctor White, which gives the succession in detail and shows the increasing thickness of Conemaugh, the intervals being 607 to the Upper Freeport, 807 to the Clarion, and 845 to the Pottsville, which shows

	Feet
1. Sandy shales, very hard	55
2. Pebbly sandstone	117
3. Dark slate	31
4. Pebbly sandstone	15
5. Sandy shale	37
6. Light shale, show of *coal*	30

285 feet, with 111 feet of mostly red shale to the limestone below. Here one finds the beginning of a change, which is complete in the next section, the record of a well at Joetown, 9 miles southwest from Mannington, which shows

	Feet
1. Sandstone	42
2. Black slate and limestone	38
3. Sandstone	185
4. *Coal bed*	2
5. Sandstone	18
6. Black shale	38
7. Sandstone	105

428 feet and resting on the limestone. At Fairview a thin coal bed is shown at 11 feet above the Pottsville; at Mannington it is in shale at 21 feet, while here it is represented by 5 feet of black shale. Number 3 is divided by 3 feet of black shale at 32 feet from the top. The upper part of the section, numbers 1 to 4, is that which is familiar in Monongalia, Wetzel, and northern Marion, equivalent evidently to the Homewood, Mercer, and Connoquenessing, with the Sharon coal bed (Campbells Creek) underlying the last. The interval from the Pittsburg coal bed to the Great Limestone is 1,243 feet at Fairview, 1,241 feet at Mannington, and 1,240 feet at Joetown. The section below number 4 is clearly equivalent to the red rock and other materials between the Sharon coal and the Limestone, of which one finds at Fairview 165 feet, at Mannington 111 feet, and here 0 feet, while the interval from number 4 to the limestone is 161 feet.

At about 15 miles west from Joetown, a well in Wetzel county shows the Roaring Creek and Pottsville in contact, the top of the latter being at 809 feet below the Pittsburg coal bed, the succession being

		Feet
1.	Sandstone	62
2.	Slate	63
3.	Sandstone	10
4.	Slate, shells, limestone	35
5.	Sandstone	50
6.	Black slate	63
7.	Red rock	10
8.	Sandstone	56

in all, 349 feet, and separated by 15 feet of shale from the Limestone. The section is shorter, as is to be expected. The presence of the red rock is important as showing the equivalence of the lower part of the section. At probably 20 miles west from Joetown, in Tyler county, and about 12 miles southwest from the last locality, a record shows the Roaring Creek in contact with the Pottsville.*

At 3 or 4 miles southeast from Joetown, a well on Laurel run, in Harrison county, shows, beginning at 702 feet below the Pittsburg,

		Feet
1.	Sandstone	270
2.	Limestone (?)	35
3.	Sandstone	95
4.	Black slate	48
5.	Sandstone	20

separated by 93 feet of "limestone and slate" from the Limestone. At Joetown the top of the Roaring Creek sandstone is at 696 feet below the Pittsburg; if the conditions remain as at that place, only about 150 feet of the top sandstone belong to the Pottsville. There is a replacement of the bottom sandstone by shale, so that instead of 108 feet, only 20 remain. The Connoquenessing ends with number 3, and the Sharon coal bed, if present, should be in the upper part of number 4. The interval from number 3 to the Limestone is 161 feet. Here, as at the preceding two localities, one finds in the union of the Roaring Creek and Homewood sandstones the condition observed 20 miles southeast in the Webster boring, a notable condition along much of the eastern border.

The variability of the section is shown by the record of a well at Browns Mills, in Harrison county, only 8 miles south from Joetown, which is in notable contrast with the records at Joetown and Laurel run. The place of the Upper Freeport coal bed is at 592 feet below the Pittsburg; thence for 300 feet there are only "black slate and shells;" so that, beginning at 892 feet, one finds

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*I. C. White: Op. cit., vol. i, pp. 239-240, 241-242, 341-342, 346; vol. ii, pp. 390-391.

	Feet
1. Sandstone	30
2. Black slate	30
3. Black sand	10
4. White sand	5
5. Black slate	10
6. Black sand	55
7. White sand	102
8. Slate and shells	8

with perhaps 100 feet of shales and limestone to the limestone. It may be that here there is a local thickening of the Allegheny, but the section is again that which is familiar in the northern counties, with the 157 feet of Connoquenessing as practically the lowest member. At Clarksburg, in Harrison county, about 10 miles southeast from Browns Mills and 11 miles east of south from Joetown, a record shows

	Feet
1. *Upper Freeport coal bed* (?)	
2. Sandstone and sandy shale	114
3. *Coal bed*	1
4. Black slate	21
5. Sandstone	28
6. *Coal bed* and slate	4
7. Sandstone	40
8. Slate	14
9. Sandstone	174
10. Black slate	72
11. Sandstone	10

to red beds. Here one finds the sandstone beginning directly under the coal bed, and almost continuous for 396 feet, there being in the interval only 40 feet of clay and coal beds. This condition recalls that at Webster, and it is found measurably at Long Run, in Doddridge county, 15 miles southwest from Browns Mills and 22 miles west from Clarksburg, for the sandstone is almost continuous from the Freeport to the upper portion of the Pottsville, which there is a sandstone 143 feet thick. The lower part must be shaly, for the driller reports only "slate, shells, and limestone" 230 feet to the limestone. In northern Doddridge, 10 miles west of north from Long Run and about 20 miles south of west from Joetown, the record, beginning at 864 feet below the Pittsburg, shows seven alternations of shale and sandstone, in all 240 feet, with underlying beds

	Feet
1. Blue slate	30
2. Red slate	75
3. Black slate	25
4. Limestone	22
5. Sandstone	40

in all, 192 feet to the limestone. Doctor White would place all of this in the Lower Carboniferous. It certainly is equivalent in great part to the red rock and associated beds of the more northerly sections, as has been observed already at several localities. The blue slate of this section most probably belongs to the Pottsville. Whether or not the red slate is Shenango will be referred to in another place. At Oxford, in Doddridge county, 15 miles southwest from Long Run, the section is in contrast with those already given, for, underlying 277 feet of shale, one has

	Feet
1. Sandstone	55
2. *Coal bed*	3
3. Black slate	43
4. Sandstone	53
5. Black slate	10
6. *Coal bed*	3
7. Black slate	11
8. Sandstone	40
9. Dark slate and sandstone	19

giving a total of 272 feet to the limestone. A coal bed is shown at 15 feet above number 1. At Long Run the interval from the Pittsburg to the Lower Carboniferous limestone is about 1,200 feet. Here it is 1,168 feet, or 32 feet less, though in the interval the Allegheny is 45 feet thicker. It is evident that the lower part of the section north from Long Run has disappeared in this direction, and that the whole of this Oxford section is Pottsville, the Shenango shales being certainly absent. The coal beds are in the places for Mercer and Quakertown, and number 9 represents the Sharon shale. At Harrisville, 15 miles west, in Ritchie county, one finds, beginning at 1,236 feet below the Washington coal bed, or about 825 feet below the Pittsburg, a series 442 feet thick and separated by 8 feet from the limestone below; and at Cairo, 3 miles west, the series is 431 to 460 feet thick, with a heavy sandstone at the bottom. These sections look much like a thickening of the Oxford section, and so to be Pottsville throughout. A section in the western edge of Ritchie county shows

	Feet
1. Sandstone	57
2. Shale	99
3. Sandstone	137

a notable decrease, but the loss has been mostly in the shales dividing number 3. Here those three beds are but 19 feet thick. In a well near Cairo the shales are 164 feet.

Wood county extends westward from Ritchie to the Ohio river. It is difficult here to determine the Pottsville. A record in northwestern part of the county shows two plates of sandstone, 120 and 100 feet respectively, separated by 90 feet of blue and black shale. The lower plate rests on the limestone. In much of the county the Mauch Chunk is wanting, and the Pottsville is continuous with the Logan or separated from it by a shale mass so thin that drillers seldom note it. At Parkersburg, on the Ohio, the two sandstone plates are present, each 50 feet and separated by 25 feet of black shale. The Logan is at a few feet below.*

Returning now to the easterly side, one finds at Vadis, on the Lewis-Gilmer line and 15 miles southeast from Oxford, the Pottsville, beginning at 868 feet below the Pittsburg, as follows:

	Feet
1. Sandstone	20
2. Shale	7
3. Sandstone	18
4. Shale	45
5. Sandstone	80
6. Shale	67
7. Sandstone	53

One is now approaching the region where the Pottsville begins to thicken, and at Glenville, in Gilmer county, 12 miles west of south from Vadis, the top of the Pottsville is at 875 feet below the Pittsburg coal bed. The section is

	Feet
1. White sandstone, with gas	18
2. *Coal bed*	3
3. Black slate	45
4. Gray sandstone	11
5. Black slate	235
6. White sandstone, with gas	164
7. Blue and black slate	32
8. White sandstone	24
9. Black slate	50

with 135 feet of blue and red shale to the limestone. Taking the shales as Shenango, the thickness of Pottsville is 545 feet. The "Clarion" (?) coal bed is at 8 feet above number 1. The coal bed, number 2, belongs to the Mercer group. The incomplete record of a well at Stumptown, on the Gilmer-Calhoun border and 12 miles southwest from Glenville, shows the same condition; for, beginning at 895 feet below the Pittsburg, the section is

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*I. C. White: Op. cit., vol. i, pp. 248, 250, 285, 302-303, 304, 318, 321, 325, 333. Bull. no. 65, pp. 129, 189.

	Feet
1. Sandstone	113
2. Limestone, shale, and slate	287
3. Coal bed	9
4. Limestone (shale)	26

or 435 feet, and the bottom not reached. The shale, number 2, the same with number 5 of the Glenville record, is a notable feature under several counties; but the beds vary much, for in a Calhoun County well, probably 10 or 12 miles northwest from Stumptown, the shale is broken up and the thickest body is but 145 feet. At Burning Springs, in Wirt county, 12 or 15 miles northwest from the last and at the same distance southward from Cairo, in Ritchie county, the record, beginning at 890 feet below the Pittsburg, is

	Feet
1. Sandstone	60
2. Shale	118
3. Sandstone	58
4. Shale	14
5. Sandstone	110

Returning to the south and passing into Roane county, southwest from Gilmer, one finds at Spencer, about 15 miles south from Burning Springs and 20 miles west from Stumptown, a record which, beginning at 1,282 feet below the " Washington " coal bed, shows

	Feet
1. Sandstone	29
2. *Coal bed* and slate	10
3. Sandstone	41
4. Shales	228
5. Sandstone	45
6. Slate	3
7. Sandstone	277
8. Slate	8
9. Sandstone	12

in all, 653 feet to the limestone. This is very like the Glenville section, except in increased thickness. The Roaring Creek sandstone, 85 feet thick, is at 5 feet, and the Mahoning at 208 feet above number 1. The coal bed at 8 feet above the top of the Pottsville in the Glenville section is represented here by 5 feet of black slate. Another record at 10 miles southeast in this county shows a somewhat similar succession, with the shale 200 feet thick and resting on 197 feet of sandstone. The total thickness is 647 feet. The great increase has been distributed throughout the section, and the distinction between Upper and Lower Pottsville is clear.

With these one comes to the end of tracing, for records are few toward the west and south. At Ravenswood, in Jackson county, 25 miles west from Spencer, the Pottsville appears to consist of two sandstone plates, 47 and 85 feet, separated by 33 feet of black slate; but at Letart, in Mason county, 10 miles farther west, the section is

	Feet
1. Sandstone	35
2. Shale	115
3. Sandstone	20
4. Shale	165
5. Sandstone	60

in all, 395 feet, resting on the limestone. A well opposite Gallipolis, Ohio, and about 12 miles southwest from Letart shows the interval from the Pittsburg coal bed to the limestone to be only 1,125 feet, almost 400 feet less than at Spencer. The decrease is due very largely to loss in the Pottsville, but in part to decrease in the Conemaugh, for there the bottom of the Mahoning sandstone is at 597 and the Kittanning (Stockton) coal bed is at 660 feet below the Pittsburg. The Kittanning rests directly on

	Feet
1. Sandstone	213
2. Shale	33
3. Sandstone	170

with 45 feet of slate below to the limestone. The upper part of number 1 is the Roaring Creek sandstone of the Allegheny. Number 3 is the Sharon sandstone.*

Winfield, in Putnam county, is about 28 miles southeast from Gallipolis and 40 miles southwest from Spencer. A complete section from the Pittsburg coal bed to the bottom of the Pottsville is obtained here by uniting the measurements reported by Doctor White and Mr Campbell. It is as follows:

		Feet
1. *Pittsburg coal bed*		
2. Interval	Conemaugh	539
3. Mahoning sandstone		70
4. Coal and shale, *Upper Freeport*	Allegheny	20
5. Sandstone		108
6. Place of *Stockton coal bed*		
7. Shale		52
8. Sandstone		20
9. Shale		37

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* I. C. White: Op. cit., vol. i, pp. 257-258, 260, 262, 264, 274, 282; vol. ii, pp, 397, 398-402.

		Feet
10. Sandstone	Upper Pottsville	21
11. Shale		15
12. Sandstone		19
13. Shells		45
14. Shale		10
15. Sandstone		20
16. Shale		15
17. *Coal* and shale		25
18. Sandstone		45
19. Slate		45
20. Sandstone		15
21. Shale	Lower Pottsville	20
22. Sandstone		275

At Lock number 6, 20 miles southeast from Winfield, 35 miles south-southwest from Spencer, and 5 miles northwest from Charleston, the succession, according to Doctor White, is

		Feet
1. *Pittsburg coal bed*		
2. Interval	Conemaugh and Allegheny	750
3. Shales and *coal*		45
4. Sandstone		35
5. Shales and shells	Upper Pottsville	220
6. Sandstone		10
7. Shales and shells		40
8. Sandstone		50
9. Shale		10
10. Limestone		35
11. Sandstone		45
12. *Coal bed*		3
13. Sandstone		7
14. Slate		35
15. Sandstone	Lower Pottsville	480

The rapid decrease of the lower members northwestwardly is shown by these comparisons:

	Charleston. Feet.	Lock 6. Feet.	Winfield Feet
Pittsburg to Stockton	800	750	737
Stockton to Lower Carboniferous	1,155	975	692*

CORRELATION

The reader who has followed this tracing of the Pottsville section is ready, doubtless, to unite with the writer in a pious expression of relief. It remains, however, to give a general summary of the relations, and to

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*I. C. White: Op. cit., vol. ii, pp. 400, 401.
M. R. Campbell: U. S. Geol. Survey folios, Charleston.

tabulate, as far as possible, the synonymy of such beds as are of stratigraphical importance.

In the preceding description, the plane between Upper and Lower Pottsville was drawn on top of the Sharon sandstone.

Crossing the Anthracite fields northwardly, one sees that the Pottsville column decreases rapidly, for the most part owing to successive disappearance of the lower members, so that in much of the northern field even the Sharon sandstone has but an insignificant representative. The loss in the lower portion continues westwardly, so that in Wyoming and Sullivan counties even the Sharon and some overlying beds have disappeared. Only the upper members of the section are present along the Allegheny front in Pennsylvania, but the whole of the Upper Pottsville, as well as the Sharon and some sub-Sharon beds, make their appearance along this line in Maryland, as shown by the Potomac sections. Thence southward, along the eastern border of the basin, the Lower Pottsville increases by successive additions of new members below—sandstone, conglomerates, shales, and coal beds—as well as by thickening of the upper beds, until on New river, of West Virginia, it is the great New River series of Fontaine, which is 1,400 feet thick in Doctor White's Nuttallburg section. Southwestwardly the increase continues until the maximum is reached in southwest Virginia and northern Tennessee. Thence southward, along the general line of outcrop, in Tennessee, into Alabama, the section shortens through loss of some lower members, as well as by thinning of the higher beds. Meanwhile, in the same direction, the Upper Pottsville expands in a similar way—by addition to the lower part of the section—while the upper members for the most part expand less rapidly; but as the Kanawha river is approached the expansion becomes notable throughout, and the great thickness observed in central West Virginia is maintained into northern Tennessee, where one reaches the last exposure of the Upper Pottsville.

Along the northern border the Sharon sandstone and immediately overlying beds reappear in the area studied by Mr Ashburner and Doctor Chance, and thence along the northern border of Pennsylvania one has the grouping offered by Doctor White:

Homewood sandstone.
Mercer group, shales, coals, and limestones.
Connoquenessing sandstones, with Quakertown shales and coal.
Sharon group, shales and coals.
Sharon sandstone.

This is the succession in Ohio along the northern and much of the western border, though at the extreme northwest there is a great thickening of the Lower Pottsville, which attains fully 175 feet in some places and clearly has a new member in the lower portion ; but in Ohio the western border lies for the most part far east from the old shore line, so that for some distance there is simply the northwest Pennsylvania section, with the Sharon sandstone somewhat irregular in occurrence.

As one approaches Jackson county, in southern Ohio, where the beds extend westward farther than in the northern part of the state, lower members of the Pottsville reappear, and one recognizes there the two members of the Sharon, with the Jackson Shaft coal bed between them. No further change appears until one has passed, in Kentucky, to 40 or 50 miles south from the Ohio river, where there is a mass of shales underlying the lowest Ohio bed. Thence southward the change is very marked, so that in Tennessee one finds appearing below these shales the Bonair and Etna sandstones, which persist to the last exposures in Alabama, with a varying thickness of beds below them, to the Lower Carboniferous. Meanwhile a change takes place in the Upper Pottsville. Until one has gone southward 40 or 50 miles into Kentucky, the section shows little variation except in the loss of its limestones, but there the column quickly expands throughout, so that in southern Kentucky and northern Tennessee the conditions are as on the eastern border. In much of Tennessee, as well as in northern Alabama, the Upper Pottsville has been removed by erosion, but it reappears in the Warrior, Coosa, and Cahaba fields of Alabama, evidently greatly expanded and bearing little resemblance to any sections obtained in northern Tennessee.

Within the basin, beginning at the north, one finds the Lower Pottsville, represented by the Sharon sandstone, disappearing quickly toward the south, not to reappear until one has gone some distance into West Virginia. The great thickness assigned to the Pottsville in Clearfield county is to be explained by the absence of the Shenango shales and lower beds, so that the Pottsville and Logan are continuous. There is good reason for believing that there one has only the upper members of the section. In the preceding pages Mr W. G. Platt's Red Bank section in Armstrong county has been referred to the Pottsville in deference to the opinion of one for whose acumen the writer has great respect ; but the conditions observed farther south and southeast in Indiana and Westmoreland counties seem to forbid this reference, and to support Mr Platt's contention that the limestone is not Mercer, but rather the Silicious (Tuscumbia) of the Lower Carboniferous, and that the great underlying sandstone is Pocono (Logan). The writer is convinced that there the Pottsville is represented only by its highest members, the Homewood and upper Mercer, the lower members of the Pottsville having thinned out eastwardly and southeastwardly.

It seems probable also that Stevenson erred in his determination within Westmoreland county, and that he referred too much to the Sharon horizon, his conclusions being at variance with the results of borings in the Monongahela valley, within both Westmoreland and Fayette counties. This matter will be examined carefully on the ground prior to preparation of the discussion of the geographical conditions.

In West Virginia the Lower Pottsville reappears at some distance south from the line of the Baltimore and Ohio railroad, and, as has been seen in the study of oil well records, new members are added below toward the south, though with irregularities, which possess much interest in another connection. Southward from the Kanawha the section approximates more closely to that along the eastern border, until in Kentucky and northern Tennessee it is practically the same. The Upper Pottsville varies in much the same way, increasing slowly throughout, until beyond the Kanawha one finds the great increase in the lower part of the column with less notable increase in the upper.

Further reference to these conditions is unnecessary in this connection. In a later portion of this work the detailed discussion will be given.

The distinction between Upper and Lower Pottsville is very marked in the greater part of West Virginia, Virginia, and northern Tennessee, on the eastern side of the basin, as well as in much of Ohio; in Kentucky and northern Tennessee along the western side. It is necessary to designate them by special terms. The only name which has been applied to the Upper Pottsville, as defined in this paper, is that of Beaver series, used by J. P. Lesley in 1878; but several correspondents in referring to the formation have spoken of it as the Mercer, a good term. Kanawha of Campbell can not be employed, as it embraces important horizons of the Allegheny and its use would lead to confusion. Several terms have been applied to the Lower Pottsville, in whole or in part. Lee of Campbell, in southwest Virginia, does not include the highest members in the locality where the name was first applied. The earlier name, Rockcastle of Crandall, was given in southern Kentucky, where the lowest members are wanting; but in the same report it was applied to the Pine Mountain region, where the section is practically complete.

SYNONYMY

The synonyms and distribution of the more important horizons are

BEAVER.

Homewood sandstone...... (I. C. White.)	Homewood of I. C. White, Johnson Run of Ashburner, Piedmont of Ashburner and Stevenson in Pennsylvania; Piedmont and Homewood of I. C. White and

	Martin in Maryland; Homewood and Tionesta of Orton in Ohio; not named in Kentucky, where it is frequently shale; not reached in most of the Tennessee field; Homewood of I. C. White, "salt sand" of drillers, in part, in West Virginia.
Mount Savage coal bed (J. P. Lesley.)	Tionesta of I. C. White, Alton Upper of Ashburner, Mount Savage of Stevenson in Pennsylvania; Mount Savage of Lesley and others in Maryland; Tionesta, Wartman, and Newland of Orton, Bolivar of Newberry in Ohio; number 4 and Hunnewell of Crandall, Lower Splint of Hodge in Kentucky; coal P of Bradley in northeastern Tennessee; Lower Splint of Campbell and Stevenson in southwestern Virginia; Coalburg (?) in southern West Virginia.
Mercer shales (I. C. White.)	Upper portion becomes sandstone in central part of Kentucky, persists as such in Kentucky, northern Tennessee, and southwestern Virginia, where it is the Gladeville sandstone of Campbell.
Mercer limestones (I. C. White.)	Present in only a small part of northwestern Pennsylvania; present, but irregularly, in Ohio almost to the Ohio river; the Lower is the Blue or Zoar of Newberry; absent in other parts of the basin.
Upper Mercer coal bed (I. C. White.)	Upper Mercer of I. C. White, Middle Alton of Ashburner in Pennsylvania; Bruce of Newberry, Strawbridge of Read, Bedford of J. T. Hodge, Upper Mercer of Orton in Ohio; not definitely recognized in Kentucky, but may be coal 3b of that state and unnamed bed under Gladeville sandstone in southwestern Virginia; not recognized in Tennessee and southern West Virginia.
Lower Mercer coal bed (I. C. White.)	Apparently the persistent bed. Lower Mercer of I. C. White, Lower Alton of Ashburner, probably Alpha of northern Anthracite field, coal A of Bernice in Pennsylvania; coal 3 of Newberry, blue limestone coal, Flint Ridge, Lower Mercer of Orton in Ohio; Elkhorn, Jellico, Peach Orchard, McHenry of Crandall, Twin bed of Lesley in Kentucky; Bradley's coal O in northern Tennessee; represented in southwestern Virginia by either the Kelley or Imboden of Campbell and Stevenson, or perhaps by both of those beds; Winnifrede of Kanawha and southern West Virginia; eroded from most of Tennessee and northern Alabama.
Connoquenessing sandstone. (I. C. White.)	Upper and Lower of I. C. White, separated by Quakertown shales and coal bed, Kinzua of Ashburner in Pennsylvania; Massillon of Newberry and others

	in Ohio; frequently present as sandstone in Kentucky, as well as in many sections within West Virginia, but not named in either state except in northern part of the latter; Connoquenessing of the Maryland reports.
Quakertown coal bed (I. C. White.)	In Quakertown shale of I. C. White in Pennsylvania and northern West Virginia; Quakertown of Orton in Ohio; coals 2 and 2a of Crandall and Hodge in Kentucky; not identified in southwestern Virginia; Cedar Grove (?) of Kanawha river.
Sharon coal bed (H. D. Rogers.)	Sharon and Campbell's Ledge of I. C. White, Marshburg of Ashburner in Pennsylvania; Block, Brier Hill, Massillon, and Wadsworth of Newberry, Sharon and Wellston of Orton in Ohio; number 1 of Crandall and Hodge, Laurel of Norwood, Pittsburg of Crandall and Campbell, Adamsville of Lesley, Warfield of Lesley and I. C. White in Kentucky; not named in Tennessee; not identified in southwestern Virginia; Campbells Creek, Sharon, and Cook of authors in the Kanawha region.
Rockcastle.	
Sharon sandstone (H. D. Rogers.)	Sharon of I. C. White, Olean of Ashburner, Garland of Carll in Pennsylvania; Sharon conglomerate in Ohio; conglomerate in northern and central Kentucky, Corbin of Campbell in southern Kentucky; Corbin in northern Tennessee; Dotson of Campbell in southwestern Virginia; Nuttall of the Kanawha region, "salt sand" in part of drillers in West Virginia.
Jackson Shaft coal bed (E. B. Andrews.)	Jackson Shaft of Andrews and Orton in Ohio; Barren Fork of Crandall in southern Kentucky, not named in northern part of the state; represented probably by several beds in southeastern Kentucky; present in Harlan county, Kentucky, but not named by Campbell; persistent in West Virginia, Virginia, and northern Tennessee, but not named by observers; probably bed underlying Sharon sandstone on the Potomac; disappears northward in central Ohio and West Virginia; removed by erosion from southern Tennessee and northern Alabama.
Rockcastle sandstone (M. R. Campbell.)	The hornstone bearing part of the conglomerate in Ohio underlying Jackson Shaft coal bed; Rockcastle of Campbell in Tennessee and southern Kentucky; "Bee rock" of Campbell and Stevenson, Bearwallow (?) of Campbell in southwestern Virginia; removed from northern Alabama and most of southern Tennessee; may be Gibson's Third conglomerate in Alabama; present in middle and

	southern Anthracite fields of Pennsylvania, but does not extend into other parts of that state or into northern West Virginia.
Sewanee coal bed (J. M. Safford.)	Wanting in Ohio, in Pennsylvania, except southern and middle Anthracite fields, and in most of West Virginia north from the Kanawha; wanting in northern Kentucky, but present in southern Kentucky, where it is probably the Main of Lesley; Main Sewanee of Safford, Coal Creek, Harriman, Rockwood, etcetera, of authors in Tennessee; present but not mined or named in northern Alabama; Sewell in Kanawha region of West Virginia.
Bonair sandstone (M. R. Campbell.)	Wanting in Pennsylvania bituminous areas, in northern West Virginia, in Ohio, in most of Kentucky; Bonair of Campbell, Main of Safford in Tennessee; Upper Conglomerate of McCalley, Second Conglomerate of Gibson in Alabama; Raleigh of Campbell in West Virginia.
Cashie coal bed (A. M. Gibson.)	Wanting in Pennsylvania bituminous, in most of northern West Virginia, in Ohio, in Kentucky; not named in most of Tennessee; Sewanee of Colton in southern Tennessee and of McCalley in Alabama; is very near place of Campbell's Beckley coal in southern West Virginia; a still lower bed in Tennessee and Alabama is at the place of Fontaine's Quinnimont.
Etna sandstone (J. M. Safford.)	On west side of basin extends northward only to middle of Tennessee, on east side to probably 50 miles north from New river in West Virginia; Cliff sandstone and Lower Etna conglomerate of Safford in Tennessee; Cliff sandstone and Millstone grit of McCalley in Alabama; probably the sandstone underlying Quinnimont coal bed in southern West Virginia.
Etna coal bed (J. M. Safford.)	On west side extends northward only to middle of Tennessee; represented in West Virginia south from New river by one of the Clark formation beds; Cliff, Main Etna of Safford in Tennessee; Castlerock of Georgia; Cliff of Alabama.

Lower horizons of much importance are present along the eastern line of outcrop in Tennessee and the Virginias northward to New river, but one may not attempt to make correlations, as the sections in most of Tennessee and Virginia are somewhat indefinite and details are practically wanting until one reaches West Virginia. Here belongs the "Pocahontas" coal bed, which is followed without difficulty for more than 75 miles in Virginia and West Virginia.

While the greater part of the Rockcastle has disappeared northward, so as to bring the Sharon sandstone and even higher beds into contact with the Lower Carboniferous within the bituminous areas, it seems wholly probable that the whole or a very great part of the Rockcastle is present in the southern Anthracite field, where the "Lykens Valley" coals are likely to prove equivalents of beds seen in the southern part of the Appalachian basin.

Some matters connected with these correlations need especial consideration.

The Kanawha Valley

In the Virginia report for 1839 Professor William B. Rogers described the beds along the Kanawha, and drew the plane of separation between the Upper and the Lower Coal Series at the top of a calcareous sandstone, fossiliferous, and 140 feet above the Black flint. No very definite explanation of the terms was given in this report, but in that for 1840 the Kanawha deposits above Charleston are placed in the "Lower Coal Group," which is succeeded by the "Lower Shale and Sandstone Group," extending upward to the Pittsburg coal bed.* The Kanawha formation of Campbell is almost accurately the equivalent of the "Lower Coal Group," which Rogers thought to be the same as the lower productive Coal Measures of Professor H. D. Rogers in Pennsylvania, now the Allegheny formation.

In 1871 Mr Ridgway regarded several of the Kanawha coal beds as equivalent to certain beds of the Pennsylvania Lower Coal Measures (Allegheny); and in the next year Stevenson, after a cursory examination, went somewhat further in determination of equivalents. In 1874 Professor Fontaine came to the same general conclusion, laying stress on the fossils of the Black flint, which appeared to correlate it with a black shale underlying the Mahoning sandstone near the Pennsylvania line. In 1876 Mr Maury recognized the Kanawha beds as equivalent to the Pennsylvania Lower coals, but he went no further in detailed determination than to assert that the sandstone overlying the Black flint is the same with the Mahoning of Pennsylvania, now taken in Doctor White's grouping as the lowest bed of the Conemaugh.†

In 1874 Stevenson, during a reconnaissance across West Virginia, examined the greatly expanded coal bed in Randolph and Upshur counties known as the Roaring Creek coal bed. Finding there a massive sandstone of great thickness, he identified it with the Mahoning sandstone, and the underlying coal bed with the Upper Freeport of Pennsylvania. A gap of at least 60 miles intervened between the Upshur locality and the Pennsylvania line, near which, in 1870, he had made correct correlations with the Pennsylvania beds; but this evidently was not a matter worth considering. For many years no detailed study of the intervening space was made, and Stevenson's identifications were accepted as accurate. Ten years later Doctor White followed the Roaring Creek coal bed from Upshur county to the Kanawha river, and found it to be the equivalent of the Stockton coal bed, which, by common consent of all previous observers, had been regarded as practically at the horizon of the Upper Freeport coal bed. The careful tracing of the section by Doctor White evidently confirmed the conclusions of all who had gone before him.*

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* W. B. Rogers: Report of progress of the Geol. Survey of Virginia for 1839, p. 135; for 1840, p. 73.

† W. M. Fontaine: Great Conglomerate of New river, pp. 461-463.

M. F. Maury, Jr.: Resources of West Virginia, p. 196.

Several years after the publication of Doctor White's results Mr David White collected plants at several horizons along the Kanawha river. The testimony of these plants contradicted absolutely the conclusion that the Stockton is Upper Freeport, and required that a great part of the Kanawha formation be placed in the Pottsville. Still later, Doctor White, after a study of the region northward from Upshur county, suspected the accuracy of the identification of the Roaring Creek coal bed with the Upper Freeport, and suggested that the bed might be correlated with the Lower Kittanning of Pennsylvania, and that the Upper Freeport might prove to be represented on the Kanawha by the Mason coal bed. This suggestion proved to be correct in the main, for, as has been seen, the Stockton coal bed is at the horizon of Kentucky coal 6, which is the Lower Kittanning, being at only a few feet above the Ferriferous limestone. Doctor White's sections, north from the Kanawha, show conclusively that the Stockton can not be higher than the Kittanning horizon, so that it is in the lower portion of the Allegheny formation. The matter is now sufficiently clear. There is no conflict between stratigraphy and paleobotany respecting the main horizons. The conflict was but apparent, and was due solely to hasty correlations by the earlier observers.†

Of the coal beds found along the eastern outcrop north from the Kanawha none except the Campbells creek can be correlated closely with Pottsville coal beds elsewhere. Evidently the tendency to divide, shown by beds along the Kanawha, prevails for many miles northward, and

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*I. C. White: Catalogue West Virginia University for 1884–1885, p. 59.

†D. White: Pottsville series along New river, West Virginia. Bull. Geol. Soc. of Amer., vol. vi, pp. 305 et seq.

I. C. White: W. Va. Geol. Survey, vol. ii, p. 603.

Doctor White's sections are too far apart to make close identification more than conjectural.*

THE ANTHRACITE FIELDS OF PENNSYLVANIA

The stratigraphical study shows that the Rockcastle or Lower Pottsville is thickest in the Southern field, that much of the lower portion is wanting in the Middle field, and that practically the whole of the section is absent from the Northern field. The study of plant remains tells the same story; for twenty years ago Doctor White, making use of Mr Lacoe's studies, found in them the proof for his conclusion that the Campbells Ledge coal bed of the Northern field belongs near the base of his Pottsville. Mr David White's study of plants from many horizons in the Southern field leaves no room for doubting the general statement. In this work Mr White offered tentative correlations with horizons at localities in the Virginias and farther southward, tentative because they were based upon limited collections from the southern localities. These do not coincide in all cases with the conclusions reached in this paper from study of the stratigraphy; but in several instances the study of extensive collections has enabled Mr White to reach final conclusions, which, in so far as the localities studied are concerned, are in practical agreement with those suggested by the stratigraphy.†

The Anthracite fields are separated by hundreds of miles from the nearest localities at which the Lower Pottsville is shown in great thickness. The conditions in the Anthracite area were very different from those of any southern area except eastern Alabama, so that any attempt at correlation on the basis of stratigraphy would be deserving only of ridicule. The question as to whether the whole of the Rockcastle section and Lower Pottsville section is to be looked for in the Anthracite area or in the southern areas must remain without answer until study of the fossil plants has been completed.

A similar condition exists with respect to the Alabama coal fields, where a great mass of measures is found, separated by at least 100 miles from the nearest locality in Tennessee, where the upper beds have escaped erosion. The probabilities seem to be that the Pottsville, above the Bonair sandstone, is enormously expanded; but the determination of this matter also must be left for the paleobotanist, as there is nothing on which the stratigrapher may build securely.

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* That this remark be not construed as a reflection on Doctor White, it is well to state that the material published in the bulky volume ii of the West Virginia Survey is a gift from the author to his state, the work having been performed prior to his appointment as state geologist.

† I. C. White: Geology of the Susquehanna Region (G 7), pp. 41-43.

D. White: Fossil floras of the Pottsville formation; Twentieth Ann. Rept. U. S. Geol. Survey, pp. 755 et seq.

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TRENT RIVER SYSTEM AND SAINT LAWRENCE OUTLET

BY ALFRED W. G. WILSON

(Read before the Society January 1, 1904)

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INTRODUCTION

The present paper is offered as a contribution to the already voluminous literature on the origin of the basins of the Great lakes in the belief that the matter here presented not only is of great importance in the attempt to find a correct solution of the problem, but also because, so far as the writer's study of the literature has gone, the facts here set forth have been largely overlooked in the earlier studies of this question. In a paper published three years ago the writer very briefly outlined some of the facts and conclusions given here in more detail.* The important bearing which the studies then made appeared to have on the origin of the Saint Lawrence outlet from lake Ontario led him to delay fuller publication until he had been able to continue and extend the field work begun at that time. During the past two summers every locality mentioned in the context has been visited, and in many cases the writer has been able to revisit (in a few instances several times) critical points after the first draft of this paper was prepared. The absence of good maps of any kind for the province of Ontario, except some old county maps of the eastern portion of the province, has greatly hampered the work and necessitated longer and more detailed work in the field than would otherwise have been necessary.

The published sheets of the topographic map of the adjacent parts of New York state have proved of great assistance. As might be expected, the topography on the Canadian side of the Saint Lawrence is very similar to that across the boundary. One of the maps, which accompanies this paper (plate 8), prepared from the New York topographic map of a portion of this area, will thus serve to illustrate the type of bed-rock topography that is characteristic of the whole region under discussion.

The writer is indebted to Dr F. J. H. Merrill, State Geologist of New York, for copies of the Saint Lawrence sheet of the geologic map of New York state, and to Lieutenant Colonel Anderson, Chief Engineer, Department of Marine and Fisheries, Ottawa, for very detailed profiles from which the sections across the bay of Quinte were prepared. Above water-level the sections were surveyed by the writer. The other maps which accompany this paper were prepared from the admiralty charts of the bay of Quinte, the charts of lake Ontario and the Saint Lawrence river, published by the War Department, Washington, and from county maps.

The discussion deals with the topographic features of that portion of the province of Ontario which lies east of lake Simcoe and north of lake Ontario, together with that portion of New York state which borders on the eastern end of lake Ontario. The eastern limit of the area is the Thousand Island group.

GEOLOGY OF THE AREA UNDER DISCUSSION

THE BEDROCK GEOLOGY

As is well known, Saint Lawrence river, in the vicinity of the Thousand islands, crosses the Frontenac axis, a narrow neck of Archean rocks which connects the Adirondack region with the greater Archean areas of Canada. The Archean rocks, of which the Frontenac axis forms a part, underlie the eastern, northeastern, and northern part of the area under discussion. West and south of the Archean areas the region is underlain by rocks of Ordovician age, chiefly Black River or Trenton limestones. Outcropping from beneath the Black river, and also occurring in several cases as outliers on the Archean areas, are a few feet of sandstones, some of which are classed as Potsdam. It is not impossible, in Ontario at least, where they are very much less well developed than in New York state, and are usually of a somewhat different texture, that they may be contemporaneous with the lower part of the Black River formation. In the present discussion these sandstones are only of relatively minor importance. The dominant topographic features of the region are controlled either by the limestone or by the Archean rocks.

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* A. W. G. Wilson: Physical Geology of Central Ontario. Trans. Can. Inst., vol. vii, 1900-'01, p. 168 et seq.

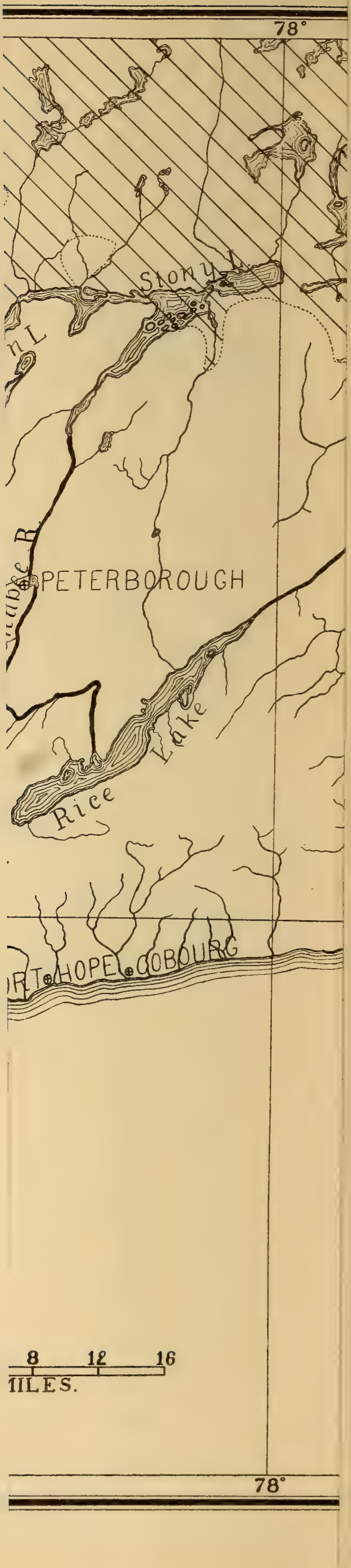
PLEISTOCENE AND RECENT GEOLOGY

In this locality, from the close of the Trenton until the Pleistocene, time is not represented by any deposits. Any that ever existed have long since been eroded away. The Pleistocene deposits are represented by typical boulder clay and by deposits of stratified sands and gravels. The distribution of these materials differs greatly in the different parts. Throughout the Archean portions of the region the deposits are confined largely to the depressions, with but very few scattered boulders or patches of till or sand and gravel on the sides or summits of the Archean ridges. In very few places does the amount of material deposited obscure the bedrock topography of the Archean terranes, the thickness rarely exceeding a few feet. The deposits are an important factor in the modification of the topography of the Archean regions as to relatively unimportant detail but not as to general features.

On the other hand, in the parts of the region underlain by Ordovician rocks the conditions are in places somewhat different. In the central parts of the district, on either side of the Saint Lawrence, the Pleistocene deposits form only a thin veneer, except very locally in a few cases. There are many large areas where almost bare rock is exposed for several square miles at a time. In very few cases does the soil cover exceed 2 feet, except in the bottoms of some of the valleys, and very frequently not even there. As the measure of relief in the district under discussion often exceeds 150 feet, and thus in comparison with the thickness of the Pleistocene deposits is very great, it is possible to determine without the slightest doubt the nature and character of the bed-rock topography of those regions. In New York state, south of Stony creek (about 6 miles south of Sacketts harbor), the bedrock topography becomes obscured by morainic deposits. But even here, particularly in the vicinity of the lake shore, certain of the features whose presence would be expected from their occurrence farther north are found to be present, partly obscured by drift it is true.

In Ontario the area whose bed-rock topographic features can be accurately determined includes the whole of Prince Edward county. Here, although there is abundance of drift as a thin veneer, the farmer in plowing is often turning over more or less decayed rock, unquestionably *in situ*, which the writer regards as probably of pre-Glacial origin, a question to which reference will be made below. The heavy morainic deposits of central Ontario lie close to the lake from near Toronto to the vicinity of Trenton. At Trenton their southern edge turns inland, and they extend eastward to near the village of Croydon. Northward they reach almost to the edge of the Black River limestones at the borders of the Archean; but they are not continuous, numerous exposures of bed rock being known north and east of Trenton. South and east of the line between Croydon and Trenton the character of the bed-rock topography can be determined without difficulty. All along the line of contact between the Black River limestones and the Archean, within the limits of the area under discussion, from the south of Carthage, in New York state, to west of lake Simcoe, in Ontario, the topographic features of the limestones are practically unobscured by drift. Outcrops without cover of any kind are very frequent, particularly in the province of Ontario, where there seems to be much less drift cover than over the similar region in New York.

Glacial or post-Glacial movements have produced one very important change. The present attitude of the region is not that which it had at the time the topographic features it now possesses were produced. There has been local differential movement which has modified the original relative attitudes of the different parts of the region. Probably there was at the same time a considerable amount of regional movement by which the general attitude (with respect to sealevel) of the whole area was altered to its present position, accompanied by certain modifications of the drainage lines. Recent process has effected only minor and local changes, such as the partial erosion of portions of the drift deposits or the local modification of the topography where differential movements or other causes had produced lake basins. One of the most noticeable of these recent changes is the blocking of the lower reaches of a number of partly submerged valleys by the formation of bars across their ends,


78°
Stony L.
n L.
abee R.
PETERBOROUGH
Rice Lake
RT HOPE
COBOURG
8
12
16
ILES.
78°

thus producing a series of small lakes bordering the eastern end of lake Ontario.

Topographic Features of the Country East and Northeast of Lake Ontario

GENERAL DESCRIPTION OF THE TOPOGRAPHY

The topography of the portion of the area underlain by Archean rocks is that of one of the partly dissected pre-Ordovician facets of the Laurentian peneplain.* In this particular locality it is characterized by the occurrence of longitudinal, often steep-sided, more or less rounded or domed ridges, with deep valleys between, characteristic of the Archean areas where they are bordered by the Paleozoics. The maximum relief rarely exceeds 150 feet. The lower portions of the depressions often form lake basins, and the longitudinal valleys are usually the basins of streams. A reference to the accompanying areal map (plate 5) will show the general longitudinal distribution of the water bodies, which, in the absence of contour topographic maps, will serve as a valuable index to the nature of the topography.

In detail it is found that between the major longitudinal valleys of the Archean areas the general surface of the tops of the intervalley ridges (where these are not too narrow) is mammillated or undulating. Everywhere the tops and often the sides of the ridges have been smothered and scoured, and all now present a surface of relatively fresh rock. As has been pointed out elsewhere,† the main topographic features, including this last characteristic, are probably in all their essential features of pre-Ordovician date.

The Ordovician limestones lie with a very gentle dip away from the Archean areas. North of the east end of lake Ontario the dip is approximately southwest. East of lake Ontario it is more westerly. Especially near the Archean regions there are local undulations and other irregularities caused by the unevenness of the floor on which the sediments were laid down. Subsequent to their deposition and before the present drainage lines were developed, erosive processes planed off the region, producing a nearly even surface, truncating the beds at a slight angle both with the dip and with the line of strike, leaving the imbricating edges of the different beds pointing toward the old land. That surface has now become somewhat warped, the lowest part being in the vicinity of the valley of the Saint Lawrence river. The general slope of

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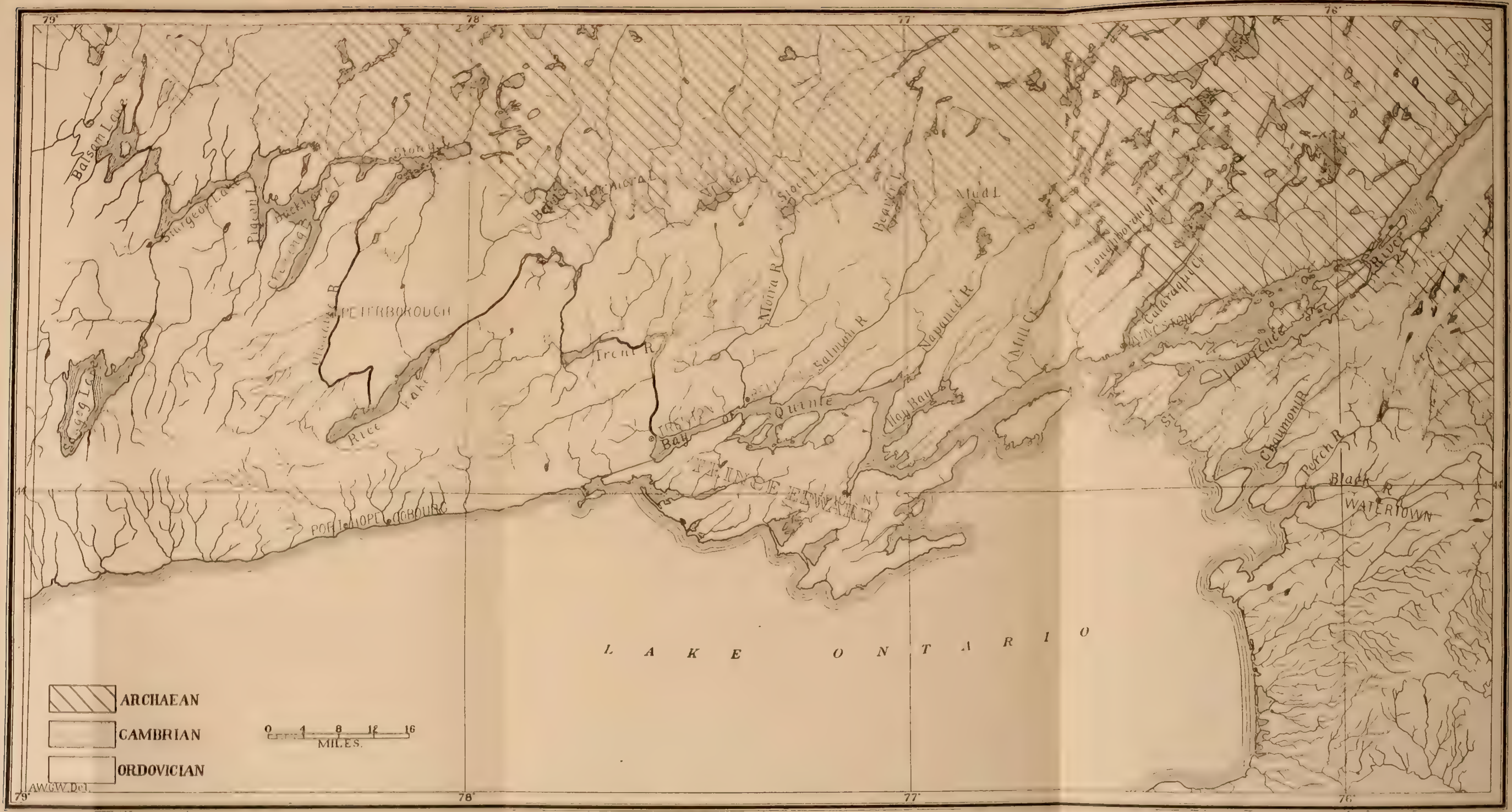
*A. W. G. Wilson: The Laurentian Peneplain. Chicago Journal of Geology, vol. xi, 1903, p. 615 et seq.

†Chicago Journal of Geology, loc. cit., p. 656.


79°
78°
77°
76°
44°
Balsam Lake
Sturgeon Lake
Pigeon L.
Buckhorn L.
Chemong L.
Stony L.
Otonabee R.
PETERBOROUGH
Rice Lake
Scugog L.
Marmora L.
Moira L.
Stoco L.
Beaver L.
Mud L.
Loughborough L.
Cataraqui Cr.
KINGSTON
St. Lawrence River
Moira R.
Salmon R.
Napanee R.
Mill Cr.
Trent R.
Bay of Quinte
Hay Bay
PRINCE EDWARD
PORT HOPE
COBOURG
Chaumont R.
Perch R.
Black R.
WATERTOWN
LAKE ONTARIO
ARCHAEAN
CAMBRIAN
ORDOVICIAN
0 4 8 12 16
MILES.
A.W.G.W. Del.

GEOLOGY AND DRAINAGE FEATURES OF THE COUNTRY NORTH AND EAST OF LAKE ONTARIO

the upland or intervalley areas north of lake Ontario is to the south, or toward the lake. All the present valleys north of lake Ontario, which have been cut in the limestone, slope toward the southwest—not, however, always in accordance with the dip, though they are in accordant positions with each other. Hence the grade of the valley bottoms is much less than the slope lakeward from the Archean areas, the length of the valleys being thus proportionally longer than the line of maximum slope from their heads near the Archean to the nearest part of the lake into which flow the streams occupying the bottoms of the valleys. The direction of flow of the present streams is not that which they would normally assume in consequence of the slope of the general surface of the country.

In New York, on the other hand, the dip of the slope-plane of the bottoms of the valleys is in nearly the same direction as that of the plane of the dip, and that of the plane of the upland surface, but the three different planes are at slightly different angles to the horizon, that of the dip being greatest, and that of the valley bottoms least. In Ontario the direction of slope of the valleys is in a direction accordant with the similar valleys developed to the south of the Saint Lawrence in New York. In Ontario these differences in direction of slope between the general surface, the plane of the valley bottoms, and the plane of the dip are so well marked in places that in the field the discordances can readily be rcognized by the eye alone.

Subsequent to their planation the limestone areas must have been uplifted and partly dissected, as in their present attitude we find that they present a well marked cuesta front toward the old land, and are dissected by a well developed system of valleys to whose existence reference has already been made. The valleys and the lowland in front of the cuesta are regarded as of later date than the plane which bevels off the upland surface, since there is everywhere a well marked discordance between the gradient curves of the valley sides or cuesta front and the very much flatter surface curves of the even uplands.

The cuesta front as it now appears is often a steep, inaccessible cliff. The height varies up to a maximum of about 150 feet. The crest of the cuesta is usually formed by heavy-bedded Black River limestones. At its base there are often found softer calcareo-arenaceous, at times argillaceous, beds. These latter, or else sandstones of Potsdam age, often underlie the narrow belt of lowland which lies in front of the cuesta, between it and the oldland. In Ontario the lowland in front of the cuesta is also frequently located on Archean rocks. These lowland areas often form basins, in which are located small, shallow lakes.

The valleys which lie on the limestones are of two types—those which discharge waters from the inner lowland into the Ontario lowland, and thus traverse the limestone belt, and those whose catchment basins are located wholly on the limestone uplands.

In general it is found that the upper parts of the valleys of the first type are very steep-sided and flat-bottomed where they traverse the cuesta. In many cases both sides are inaccessible, though not necessarily vertical, cliffs as much as 125 feet in height, with a flat-bottomed valley between. The width of the valley varies somewhat, but rarely exceeds a mile and a half or is less than half a mile. In most cases the upper parts of these valleys, near where they pass through the cuesta front, form the basins of long, narrow lakes. Such lakes as those on the Cataraqui creek above Kingston mills, Collins lake, Loughborough lake, Sydenham lake, and several others in Ontario are of this type. The water seems in some cases to be held back by a drift dam, which partly blocks the lower part of the valley. Certainly in some cases, in all probability in most cases, the present lake basin is a rock basin and the existence of the present lake is due either to warping or possibly to differential erosion by ice.

These valleys in their lower reaches toward the lake become broader. In New York the sides usually have about equal slopes, the general trend of the valley being in the same direction as the dip of the rocks. North of lake Ontario, however, where the trend is not always accordant with the dip, in many instances the southeast side of the lower portion of a valley is much steeper than the northwest side. Many of the valleys are bounded by a well marked rock escapement, which may be traced from the cuesta front along the valley side almost to lake Ontario. In their lower reaches the breadth of this first type of valley may be as much as 5 miles. The intervalley uplands in ground plan will thus have the form of a scalene triangle, with the base at the cuesta front and the apex of the triangle pointing toward lake Ontario. The inland portions nearest the cuesta are broad and flat, with very little or no soil cover. As the valley widens the gradual encroachment of adjacent sides of neighboring valleys narrows the flat intervalley area. In places, however, it so well retains its character that it ends in a wedge point which can be located in the field without difficulty, where the encroaching gradient curves of adjacent valley sides have met. In a few places close to the discharge point of the present valleys on the bay of Quinte the present surface of the intervalley ridge will thus lie below the plane of the upland surface. The majority of these valleys can be traced by aid of the soundings for some distance out from the shoreline and under the waters of the present lake Ontario.

The valleys of the second type, which head on the upland, are, in their upper reaches, mere flat shallow depressions on the limestones. As we descend any one of them we find that it gradually deepens; usually its southeast side soon becomes marked by a low cuesta-like escarpment, with a steep slope toward the valley and a gentle slope away from the crest. The northwest side is less steep than the other, but is steeper than the normal outer slope of the minor cuesta which forms the southeast side of the next adjacent valley northwestward. The valley has been formed by an incision of the rocks, and the difference in slope of the two sides is due to the relation existing between the direction of the valley and the dip of the rocks. These valleys slope, as do those of the first type, in a direction a little to the south of the strike of the rocks, but not in the direction of the dip. There are some special cases which will be referred to in the more detailed discussion of the Trent River system in a subsequent section.

It very frequently happens that valleys of the first type are continuous with longitudinal valleys developed on the Archean areas, and the head-valley lake often occupies a basin part of which is underlain by Archean rocks. The depth of the upper part of these valleys is in part controlled by the relatively harder Archean rock, the latter often being exposed in the bottom of a valley some miles away from the cuesta front, while the valley walls are of limestone.

SPECIAL DESCRIPTIONS

Trent river proper.—The most important stream in the region is the Trent river. What is usually considered as the main stream of the river system heads in a small lake in the Laurentian region of central Haliburton county. This stream, known as the Gull river, flows southwest in a valley bounded by Archean rocks to Mud Turtle lake, a partly flooded valley of the first type, noted above. Between here and Balsam lake the stream continues in this valley. Balsam lake is a broad shallow depression, located on the Black River cuesta, in which the river expands. Between Balsam lake and lake Ontario the stream follows a very remarkable zig-zag course, alternately occupying an old more or less drift-blocked rock-bound valley, usually of the first type here described, and flowing in a new channel across one of the intervalley areas. In these old valleys it usually expands to form lakes. Following down stream from Balsam lake, these lakes are named respectively Cameron, Sturgeon, Pigeon, Buckhorn, Love Sick, Deer, Stony, Clear, Katchewanaka, and Rice. Scugog lake and Chemong lake also belong to the system, though they are not on the direct line of the main stream. Between these various lakes, excepting the last two, Katchewanaka and Rice, the stretches of running water are very short and are not usually given any specific name. Between Katchewanaka and Rice lakes the main stream is called the Otonabee river. Below Rice lake to Trenton it is called the Trent river. From Trenton to lake Ontario it is usually called the bay of Quinte. It is thus found that the Trent is really a very complex system of valleys, and a more detailed description and discussion is given in the special paragraphs on the Trent River system.

The following table gives the elevation above sealevel of each of the more important lakes of the Trent River system:

	Feet
Balsam	609
Cameron	606
Sturgeon	581
Pigeon	575
Buckhorn	575
Chemong	575
Deer	565
Stony	539
Clear	539
Katchewanaka	548
Rice	378
Ontario	247

Prince Edward County topography.—Two of the principal valleys, whose union forms the bay of Quinte as it now is, have had a notable effect on the development of the topography of that part of the district known as Prince Edward county. The two parts of the bay, known respectively as the Long reach (or the Ninemile reach) and the Twelvemile reach, converge southwestward toward Picton bay. Southwest from Picton toward East lake they continue as a single well marked valley, partly drift blocked at Picton, with a steep, often cliffed, wall on the southeast side. The Long reach has intercepted any drainage which normally would have crossed Prince Edward from the northeast, and so we find that its western wall is marked by a cliff whose present height above waterlevel is about 150 feet, or whose crest rises about 185 feet above the bottom of the now partly submerged valley. There are but two minor obsequent streams that have barely incised notches in the cliff front. On the upland, west of the Long reach, head several small streams whose valleys belong to the second type of valley mentioned above. In crossing Prince Edward county toward the southeast, ten well marked low cuestas, including the one between East lake and Picton bay, with north facing steep fronts and gentle south dipping back slopes, are met with, besides a few of minor importance. It has not yet been possible to carry the detailed study of the topography far enough to determine the interrelations of all of these valleys whose existence is thus indicated, but the main features have been determined. The minor cuestas between Consecon lake and West lake, four in number, are the southeast sides of valleys of the second type which head on the upland adjacent to the Long reach. The cuestas north of Consecon lake are associated with the complex system of valleys, parts of which form the present bay of Quinte, between Trenton and the Long reach. Those south of East lake, except the one immediately adjacent to the lake, are also associated with valleys of the second type.

Other rivers in the province of Ontario.—Tributary to the bay of Quinte there are a number of other streams traversing valleys of the types here described. The largest of these is the Moira. Heading on the Archean, it runs southwest to the cuesta front at a point 5 miles west of the village of Madoc. The main stream now turns eastward along the lowland in front of the cuesta, expanding slightly at Moira lake, to Stoco lake, also in front of the cuesta. From here it passes into the cuesta through one of the valley openings of the first type and continues along the depressions for several miles. The lower portions of the valley are blocked by heavy accumulations of drift, and the river has taken a new channel, not directly associated with any of the old rock valleys, though it reaches to bed rock in several places. In the vicinity of Plainfield the Moira receives an important tributary from the northeast. This tributary heads in a direct line with Beaver lake, and occupies a valley which may be the lower course of an old valley of which Beaver lake marks the site of the upper narrow portion, the part between being drift-blocked. There are also several tributary streams of minor importance heading on the limestone uplands and occupying rock valleys which have well defined sides near their junction with the main valley.

Omitting further reference to several minor streams, the next river of importance is the Salmon river. This heads in Beaver lake a little west of Tamworth and crosses the limestone area in a well defined straight valley, easily traceable by its high, well marked rock scarps the whole way across. The Napanee river, Big creek, Mill creek, Collins creek, and Cataraqui creek all cross the limestone regions in definite, straight rock-sided valleys of the first type. Between these streams, and also in some cases tributary to them, are several minor streams occupying valleys of the second type. In the case of Cataraqui creek, it is interesting to note that in cutting downward the stream which carved the valley encountered an Archean ridge buried in the limestone, through which it has carved a narrow canyon (at Kingston mills), the valley on the limestones above and below being much broader than here—a typical "shut in" of the Missouri type, in fact.

Rivers in New York state.—The Bateau channel of the Saint Lawrence river below Kingston is a partly submerged portion of the eastern end of the Twelve Mile reach of the bay of Quinte. The American channel, as will be shown subsequently, is also one of those submerged valleys. Between cape Vincent and Sacketts harbor a number of southwest-flowing streams occupy well defined rock valleys. Of these Chaumont river, Perch creek, and the Black river cross the limestone areas in valleys of the first type. Mud creek, Muskalonge creek, and a few other minor streams occupy valleys of the second type. The most important of these streams is the Black river, which to the south of Carthage flows for a long distance in the position of a normal subsequent stream along the lowland between the limestone cuesta and the Adirondack oldland. South of Sacketts harbor there are a number of southwesterly flowing streams all of which head on the upland, and most of which show in parts at least that the valleys which they occupy, though more or less drift-blocked, are of the types here described. A more detailed reference to them is not necessary in the present discussion.

Enough has already been said to show that on either side of the present Saint Lawrence outlet we have a well marked system of southwest trending rock-walled valleys, with a number of similar rock-walled minor valleys tributary to them and joining them at accordant levels.

Before describing these valleys more in detail and before discussing their inter-relations and their relation to the Saint Lawrence outlet, it will be well to consider the question of their probable origin and its date.

ORIGIN OF THE BEDROCK TOPOGRAPHY

That these valleys are due to normal processes of stream erosion is attested by their form and shape and by the uniform accuracy of the adjustments between tributary and main valleys. North and east of Trenton and west as far as the headwaters of the Trent system, many of these valleys are found more or less occupied by drift deposits. The lowest of these deposits, as shown in the section cut by the Trent river north of Trenton and in numerous other sections along lake Ontario, is a clay till of what is probably the second glacial epoch. This till is overlain by other deposits of several interglacial and glacial epochs respectively. Beneath the till, which is rather widespread, the striated and grooved rock surface is frequently found. It is certain that many of the valleys—and thus by inference that all of them, since they are very closely alike in form and adjustment—antedate the ice-sheet which deposited the lowest till-sheet of central Ontario and produced the striated rock surface.

The direction of movement of the ice-sheet which produced the striations on the uplands was to the west of southwest in Ontario. In New York and in the vicinity of the Thousand islands it is a little more southerly, the striæ running about south 65 degrees west, true. That this westerly direction, as shown by the striæ, is the general direction of the ice movement is also shown by the direction of the longer axes of the very numerous and large drumlins in Huntingdon township, North Hastings (county), and elsewhere. The direction of the general movement of the ice on the uplands was quite independent of the trend of the valleys. In some cases it has been parallel to them, in others across them or at various angles to their axial lines. In one locality, near the head of Mill creek, striæ are found crossing obliquely downward into the valley from the northeast. At this locality the valley sides are steep cliffs and at one point the ice in its descent into the valley appears to have broken away a short piece of the crest of the cliff, producing a remarkably smooth curved surface at the very edge. Near the same locality, in the bottom of the valley about midway between the walls, striæ are found parallel to the valley sides and thus oblique to the general direction of ice movement, showing that here at least there was a local differential movement of the ice sheet, assuming that these striæ, which are but a few hundred yards apart, are of contemporaneous origin.

In another locality, just west of the town of Napanee, a cliff on the southeast side of the valley of the Napanee river is scoured from base to summit, a height of about 125 feet, although upstream above and downstream below the scoured area the same cliff shows no well marked traces of glacial erosion. There is a slight turn in the direction of the cliff line at the locality in question, and it is this fact that probably led to the unusual amount of scouring at this place.

Again, on the north side of the American channel of the Saint Lawrence river, about a mile and a half below Carleton island, there are a number of places where, in passing down into the valley, the ice has cut deeply into the cliff crest of the ancient and now submerged valley side, producing deep grooves or channels. One of these, a type of them all, is about 25 feet across, about 5 feet deep at the lowest point of the curved or rounded bottom. The angles where the curve of the bottom intersects the striated flat surface of the adjacent parts of the cliff on either side is distinct and clear. The block that carved this channel was moved down into the valley parallel to the direction of the general movement of the ice in the locality, as shown by the numerous striæ on the flat surfaces elsewhere in the neighborhood. It entered the valley in a direction making an angle of about 45 degrees with its axial direction.

In another locality on the second creek to the south of Chaumont creek, in New York state, glacial striæ on some meander spurs show that the ice which made the striæ moved across several meander curves deeply cut into the limestone without materially modifying their outline.

Some miles to the west of the particular area under discussion, along the front of the Niagara escarpment, there are found a few outlying areas, mesa-like, capped by Niagara limestone usually, that have not been carried away by the ice. One of these is known as the Milton outlier and is completely severed from the main escarpment by a deep ravine. Others of similar origin, with the valleys between them and the main cuesta partly submerged, form the islands in Georgian bay along the east coast of the Bruce peninsula. Other similar outlying areas are found in many localities in front of the Black River escarpment. Often it is found that in the rear of these outliers, when they lie some distance in front of the cuesta, there is a long train of loose angular blocks which have been dragged off the top of the outlier by the ice in its passage over the region.

In very many localities between Trenton and the line of the Niagara cuesta till sheets of several succeeding ice transgressions are found to override the till of the earlier glacial transgressions and the stratified gravels, sands, and clays of the several succeeding interglacial epochs. In a number of cases, the best known being that east of Toronto, at Scarboro, though several others occur farther east, it is known that there was a period of erosion, during which broad valleys were carved in the interglacial deposits which succeeded the lowest till sheets. The ice-sheet which deposited the sheets of till other than the lowest transgressed these valleys cut in the interglacial deposits, and in some cases partly filled them with till. In descending into them it seems to have created little or no disturbance of the underlying soft materials. In ascending on the opposite side it has crinkled and crumbled some of the strata where there were competent clay members to carry the thrust for some little distance back from the side of the valley in question In no case does it appear to have seriously modified the preexisting topography by extensive erosion of these soft deposits.

The relations of the various till-sheets and interglacial deposits between Trenton and Hamilton show that during the times of transgression of the ice, other than the first, it passed over very soft deposits, some of which lie within the valleys under discussion, without materially destroying by erosion the preexisting topography of these soft deposits. From this alone we might infer it would be highly improbable that the ice of the earlier period would have performed any more effective work on the bedrock topography. As has been shown, the bedrock features of the region are those characteristic of an area that has been exposed to stream erosion and normal weathering processes for a considerable interval of time, and subsequently have been slightly and locally modified by the ice transgression, in very small part by actual erosion, in large part by the deposition of loose debris.

As was noted above, in Prince Edward county there are large areas underlain by soft more or less decayed limestone rock with a very little sand intermingled. In places the depth of this material exceeds 4 feet. In very few places within the borders of the county are there areas with well developed striated surfaces. These surfaces are, however, occasionally found associated with the softer rock. In physical character and in composition these rocks are identical, both being Trenton limestone.

Inasmuch, then, as in certain areas it has happened that the rocks retain their striations, whereas elsewhere in the same district over large areas the rock *in situ* is very much decayed, the inference would be that the disintegration was largely pre-Glacial. That it may be so and that the soils which are still *in situ* have been left here by the ice-sheet is certainly also suggested by the apparent inability of the ice-sheet to significantly modify the rock topography by actual erosion anywhere on the limestone areas immediately north of lake Ontario.

In the vicinity of Kingston and southward in New York state it is found that fresh striated rock surfaces are much more abundant and cover larger areas than elsewhere. In these localities the old rock topography is still retained, nor is it materially modified. The fresher character of the striated surfaces is due in part to the slightly different character of the rock, and probably in large part to the proximity of the Adirondacks, from which a local glacier descended into what is now the basin of lake Ontario.

From the evidence as adduced above, it is inferred that all the essential features of the rock topography are of pre-Glacial date, and that the present valleys once formed part of what is now a dismembered river system.

TRENT RIVER SYSTEM

IN GENERAL

All that part of the province of Ontario west of the Frontenac axis and between the bay of Quinte and the Archean areas on the north is drained by the Trent river or some of its tributaries. For purposes of description the Trent River system may be considered in two sections—the Central Ontario section, comprising all the streams and lakes whose waters enter the Trent river proper above the town of Trenton, and the Bay of Quinte section, comprising that portion of the Trent river which is at the same level as lake Ontario and to which most of the larger streams in this part of Ontario are tributary.

CENTRAL ONTARIO SECTION

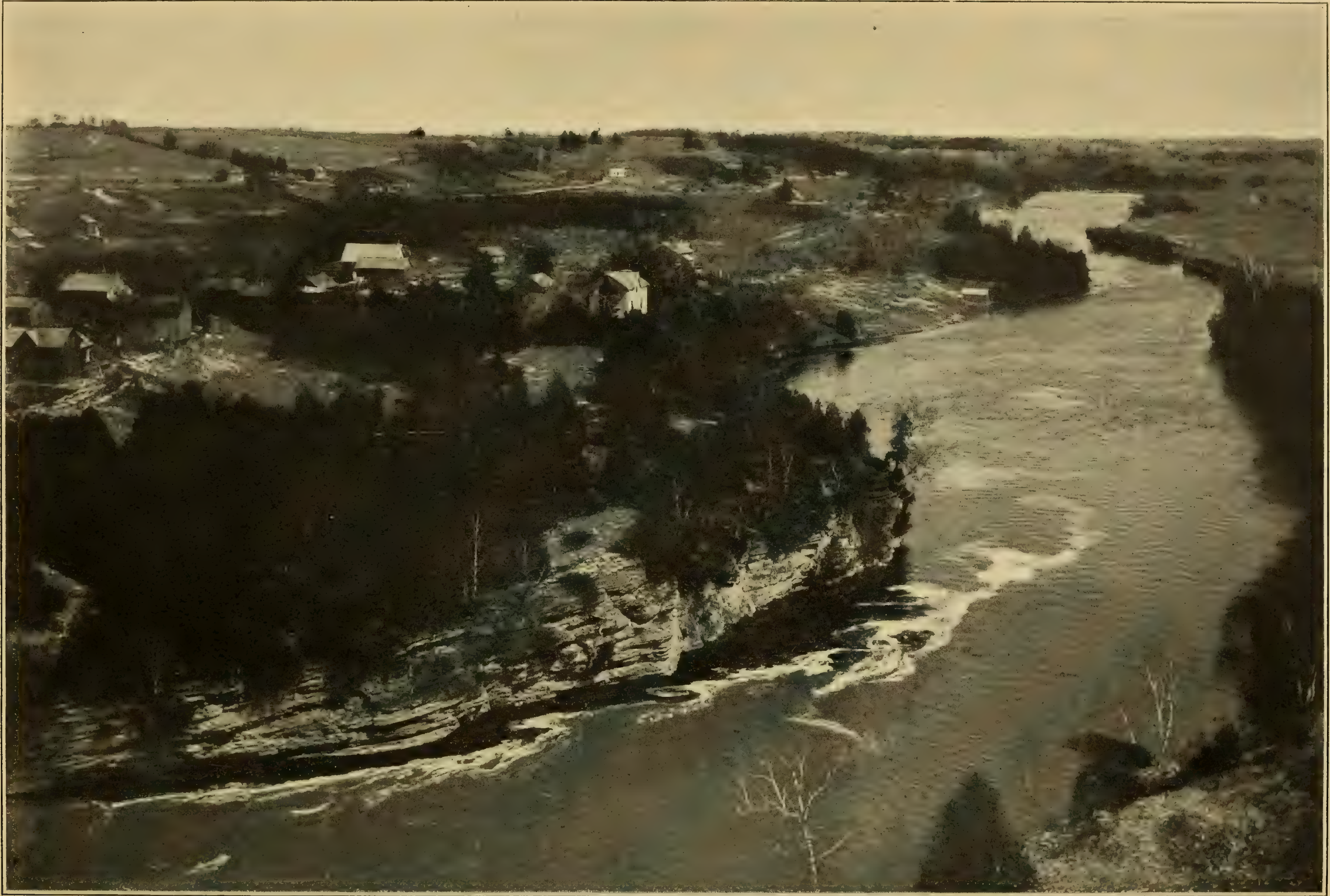
What is usually considered as the headwaters of the main stream of the Trent system is a small lake near the main divide in central Haliburton county. From this lake a stream, the Gull river, makes its way southwesterly, alternately flowing in valleys between Archean ridges or expanding into small lakes in these valleys, and traversing the ridges in a more or less southeasterly direction, usually in a series of falls or rapids into the next adjacent valley eastward. Just to the east of Norland, where the river expands to form Mud Turtle lake, it enters the Black River cuesta. The islands and shores of Mud Turtle lake are usually of Archean rock, but a little distance back from the shore, on either side, is a limestone escarpment, which reaches its best development and is highest (125 feet) on the west. This escarpment, whose height above the river gradually diminishes as we proceed downstream, borders the river to below Coboconc at the head of Balsam lake. Here it is lost among drift deposits.

Balsam lake is a broad, shallow depression on the Black River cuesta. To the west the rock divide between it and lake Simcoe is but 5 feet above ordinary lake-level, while the surface of Balsam lake is about 60 feet above lake Simcoe. Whether the Balsam Lake depression is to be considered one of the partly blocked valleys of the pre-Glacial topography is doubtful. In certain features it seems to be composed of two of these, but at present this must be regarded as uncertain. About 4 miles south of Kinmount a small stream, Corben creek, enters it from the northeast. This creek comes from Four Mile lake, a lake occupying the head of one of the valleys of the first type described above, the upper end of the lake being located on Archean rock and the sides of the lake depression being limestone.

The waters of Balsam lake flow eastward in a shallow channel, cut chiefly in drift deposits, though one broad limestone ledge, a part of the typical flat-topped intervalley upland area, has been discovered by the river. The distance to the next lake on the main system, Cameron lake, is about 2 miles. Cameron lake is an oval body of water occupying a depression which is blocked to the south by drift deposits. The Burnt river, which rises on the Archean areas to the northwest, passes into the Black River cuesta through a deep reentrant about 6 miles to the northeast and enters Cameron lake at the same place as the discharge from Balsam lake. The Cameron Lake depression is really the lower part of the valley of the Burnt river, a valley of the first type here described.

The discharge from Cameron lake, past the village of Fenelon falls, is through a new channel at the bottom of an older broad valley, with fresh cut canyon walls and a falls about 20 feet over bedrock into Sturgeon lake (plate 6). The distance between the lakes is a little over 2 miles. The depression in which the waters expand just below Fenelon falls marks a portion of one of the smaller valleys of the second type, tributary to the main valley, that occupied by Sturgeon lake proper. The Sturgeon Lake depression is the broadest and longest of the entire system. It lies wholly on limestone rock, Black river, at the northeast end, but chiefly Trenton. It is a valley of the second type, however, having no ancient opening toward the Archean. Northwest of the lake the basset edges of the limestone are found occasionally in the valley side. For the most part, however, near the depression at least, they are obscured by drift deposits. To the southeast the edges of the Trenton limestone may be found at the lake shore in a few places and in various places away from the lake. A low but well marked escarpment, with a cliff front in places, marks the southern edge of the valley and lies nearly 5 miles south of the lake. The extreme breadth of the valley is nearly 11 miles. The sides of the valley are usually evenly graded and covered with drift, and it is only in a few localities that the bed-rock outcrops. Following the depression toward the southwest both valley sides may be easily traced for over 36 miles from the discharge point of the lake. The southwest part of the valley is occupied by lake Scugog, and the river Scugog, which enters Sturgeon lake below Lindsay, flows along the bottom of the valley. The depression continues about 4 miles southwest of lake Scugog, where it is obscured by the morainic deposits which form the main topographic divide of Central Ontario. In the vicinity of Scugog lake the valley in its present attitude is very broad and flat-bottomed, and the bed-rock is completely drift-covered. The nearest outcrop which the writer has seen is at Lindsay, about half way between lake Scugog and Sturgeon lake. Another outcrop is known to occur some miles to the west of the lake and at a slightly higher level. The similarity of form between the valley sides of the Scugog depression and the Sturgeon Lake depression, where much bed-rock can be found, together with the perfect continuity of the two very strongly marked depressions, makes it highly probable that bed-rock lies not far below the surface anywhere in the vicinity of lake Scugog. The outlet stream from the northeast end of Sturgeon lake passes through a narrow young gorge cut in heavy-bedded Black River limestone to the depression occupied by Pigeon lake.

Pigeon lake is a slightly complex rock valley partly submerged. From the north there enters a small stream which rises on the Archean



YOUNG GORGE AT FENELON FALLS, TRENT RIVER, ONTARIO

North side of older valley shows in background. Photograph (by J. W. Stanton) was taken looking east from top of an incinerator 130 feet above crest of gorge, which is about 40 feet above water-level

and passes through the Black River escarpment in a narrow valley. To the northeast there is another depression through which the waters of the lake reach the Archean. The western wall of the valley is sharply defined by a steep but not cliffed rock scarp; the eastern side is less well defined. To the south the water in the Pigeon Lake depression is joined to that in Buckhorn lake through a broad channel in which there is little or no current. The channel appears to be cut wholly in drift deposits. The Pigeon Lake depression for 5 miles below the outlet channel is flooded by the waters of the lake. Southwest of the foot of the lake it is still traceable to near Omemee, where it is obscured by heavy drift deposits. The stream which flows past Omemee into Pigeon lake and rises about 20 miles southwest of the foot of the lake may possibly mark the continuation of the depression near Omemee and to the southwest.

The principal depression whose flooded upper portion forms Buckhorn lake is also a rock valley of the first type. Sandy lake, which lies to the north of the west corner of the lake, also occupies a limestone valley, through part of which the outlet stream from Sandy lake flows. The main depression extends southwest from Halls bridge. It is well marked in its northeastern extent by bounding scarps. The southwestern part is less well defined. This part of the basin seems to be a shallow upland depression rather than one of the system of valleys in which southwest running streams once flowed. The general features suggest that it was drained by an obsequent stream which flowed to the inner lowland in the same direction as the waters now flow. The waters of Buckhorn lake connect directly with Chemung lake through a broad channel bordered by very flat low-lying land. To the northeast the discharge stream flows along the lowland in front of the cuesta. It continues in this direction as far as Stony lake, there being two small falls of a few feet each in its course.

About midway between Buckhorn lake and Stony lake the river expands into a water body known as Deer lake. The depression occupied by this lake is bordered on either side by steep nearly vertical cliffs with a heavy talus at the base—the sides of a partly submerged valley of the first type. At the lower (southwest) end this valley is partly obscured by drift; but the scarps can be traced to Chemung lake. About 2 miles below the foot of the lake a portion of the valley is occupied by a small lake known as Mud lake. The water from this lake flows in a small stream into Chemung lake, which occupies the lower portion of the same valley. The rock sides of Chemung lake, at the lower parts, are completely buried beneath the drift deposits. A well boring to the west of the lake near Ennismore showed the rock scarp to be about 150 feet above the lake, and below about 20 feet of drift. To the southeast of the lake between Bridgenorth and Peterboro there are heavy morainic accumulations in the form of drumlins, and no rock exposures are known to the writer until the valley of the Trent river, referred to below, is reached. The Deer Lake-Chemung depression continues to the southwest beyond the foot of Chemung lake for a considerable distance and its course is marked by a northwest flowing stream.

Stony lake, which lies on the Archean lowland in front of the cuesta, is the most picturesque of all the lakes of the system. The partly submerged roche moutonnée surface of the Archean has given rise to numerous small and rocky islands, for the most part covered with a limited growth of coniferous or deciduous trees. To the south of the lake the Black River cuesta, rising about 150 feet above it, forms a steep escarpment. About the middle of the south side of the lake the escarpment is broken through by the upper end of one of the valleys of the first type. The flooded upper portion of this valley forms Clear lake, on the same level as Stony lake. This valley with well marked rock scarps continues to near the village of Lakefield, Katchewanaka lake above Lakefield being but an expansion of the river in a broader, flatter portion of the valley. Near Lakefield the river is turned from the valley by drift deposits, and runs in a nearly straight course, in a channel which it has incised in the drift deposits and in part into the bed-rock underneath, to some distance below the city of Peterboro. The whole course from Lakefield to Peterboro, 9 miles, is marked by a succession of rapids. The river is here flowing over one of the typical intervalley upland areas. From Katchewanaka to Rice lake this section of the river is called the Otonabee river. The last noted exposure of limestone occurs in the river bed about 2 miles below Peterboro. From Peterboro to Rice lake, 21 miles by the river, the channel is cut in drift deposits and is graded. At 12 miles below the city it turns abruptly northeast and runs in this direction for about 5 miles, rounding the northeast end of a very large drumlin, when it again turns southwest and follows a straight course to Rice lake.

Rice lake is a long, narrow lake with a maximum depth of about 25 feet, a length of 21 miles, and a maximum breadth of 3 miles. Along the whole length of its southeast shore extends a high ridge, in places rising about 600 feet above the lake. At the eastern end, near Hastings, and extending northeast from here to the next sharp turn in the river's course, the under part of this ridge is made of Trenton limestone. The greater portion of the ridge west of Hastings is buried under an immense morainic deposit of drift, which in places probably exceeds 300 feet in thickness. On the shore opposite the mouth of the Otonabee river the divide between Rice lake and lake Ontario lies less than 3 miles from the lake and about 11 miles from lake Ontario, being over 900 feet above the latter lake. On the north side of Rice lake, close to the lake, there are extensive drift deposits, and, so far as the writer is aware, no bed-rock is known. A little farther to the north, however, east of Peterboro, bed-rock occurs at a higher level than the lake. This Rice lake valley extends for a considerable distance southwest of the head of the lake as a well marked depression. The general direction of the depression is shown by the course of the stream, which enters the southwest end of the lake at Bewdley.

Tributary to Rice lake from the north is the Keene river, whose general course is in accordance with the trend of the older valleys here described. Whether it actually occupies one of these is uncertain. Heading on the upland in the same region as the Keene—a flat, swampy district of glacial deposits, including sand and gravel plains—is the Indian river, which flows in almost exactly the opposite direction and enters Stony lake near its eastern end, cascading down the front of the Black River cuesta in a well marked obsequent valley.

From the foot of Rice lake the river extends northeast in the same valley, rock walled, steepest on the south, to a short distance below Trent bridge, where the depression is less well defined. Here it widens out a little and runs on top of the limestone for a short distance in an irregular course, finally turning southeast and flowing in a succession of rapids and falls through a new channel, the lower part being a gorge, until it empties into the next old valley to the eastward.

The upper portion of this valley is occupied by the Crow river. The Crow river in its upper course runs along the front of the cuesta as a subsequent stream, being the outlet for the waters from three lakes—Round, Belmont, and Marmora—located on the inner lowland, besides a considerable amount of surplus drainage from the northeast. At Marmora it enters a well defined narrow rock-scarped valley, trending southwest, which gradually broadens. Below the junction with the Trent from the northwest this valley is well defined and rather broadly open as far as Campbellford. Below Campbellford the river leaves the old valley, which is blocked by drift, and flows in a new channel. For the first 2 miles below Campbellford it has not yet incised the rock to any great extent. South of this as far as Meyersburg it runs in a shallow post-Glacial canyon, there being a heavy rapid and falls just below Campbellford. Near Meyersburg it again turns east and widens out in a broad, shallow depression upon the limestone. This depression extends for a number of miles in either direction beyond the lowest portion occupied by the expanded river. It leaves this valley below Glencoe, turns again southwest, and flows as far as Trenton in a post-Glacial canyon cut in the limestone. In this part of its course it has incised a valley through a heavy morainic ridge, and has cut a channel in the limestone to a depth of about 25 feet and of a width of nearly 300 yards. At Trenton the river enters the bay of Quinte at the level of lake Ontario.

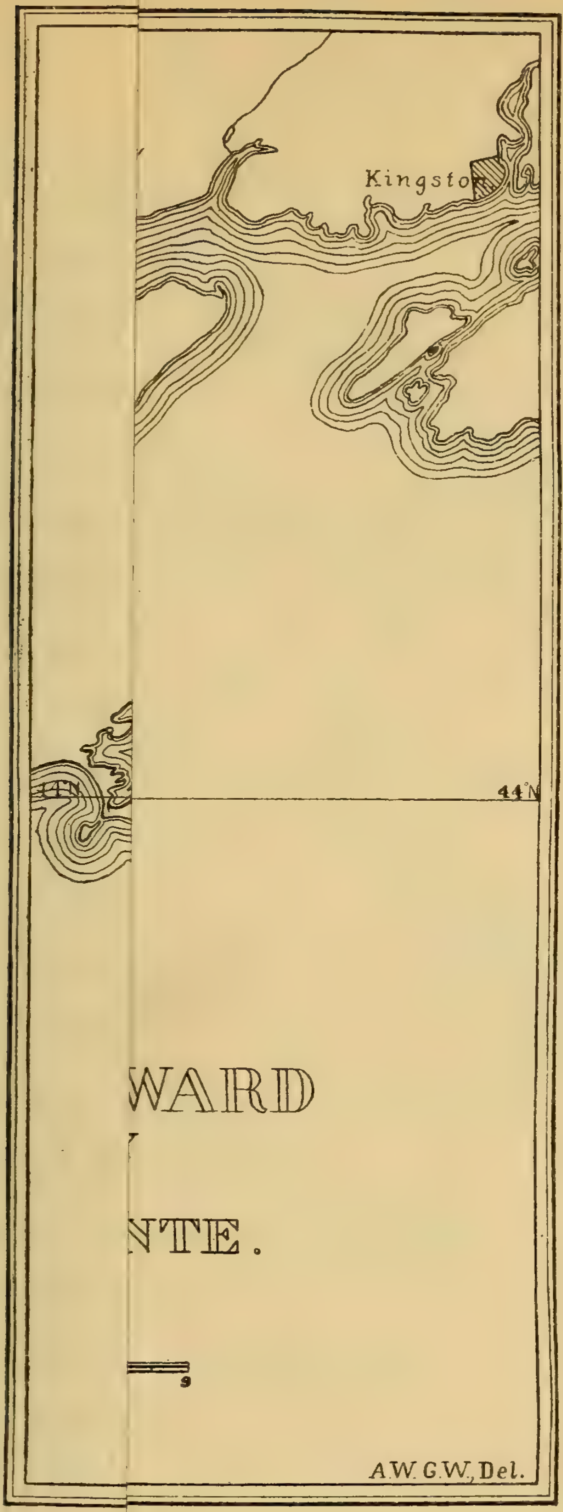
It perhaps might be noted that the present location of new portions of the present Trent river (above Peterboro and above Trenton) and of the present Moira river (above Belleville) is probably intimately associated with the retreat of the last ice-sheet across Ontario. The problem has not yet been fully investigated, but certain field studies suggest that these streams, at the localities indicated, originally flowed along a valley between the morainic deposits to the west and the front of the retreating ice-sheet on the east.

BAY OF QUINTE SECTION

In general.—A reference to the accompanying map (plate 7) will show that the bay of Quinte is naturally divisible into three distinct sections. A closer examination in the field shows that the first of these sections, that between Trenton and Desoronto, though rock-bound on both sides throughout its length, is really a complex of several valleys. The other two natural divisions—the Long reach and the Twelve Mile reach are less complex.

Trenton-Desoronto division.—The Trenton-Desoronto section naturally falls into two subdivisions—that between Trenton and Belleville (or Rossmore on the Prince Edward side) and that between Belleville and the Telegraph narrows just west of Desoronto. The first of these sections is one (possibly two) of these rock valleys with lightly scarped sides (rising 50 feet above water-level). It does not seem to be associated with the valley occupied by any modern stream (plate 7, section I). Toward the west it is drift-blocked. West of the west end of the bay of Quinte, on the other side of a low limestone divide, is another valley, also unconnected with any modern stream. Parts of the rock ridge which bound this depression on the south are exposed at Presqu' Isle, where they form a scarp facing the north and rising 35 feet above present water-level. The rocky ridge which forms Presqu' Isle is joined to the mainland by a long sand neck formed across the outlet of this valley by the waves of lake Ontario.

The only tributary of importance which enters the western section of the bay of Quinte is the Moira. As already noted, this flows as a subsequent stream in front of the Black River cuesta for nearly 15 miles,


Kingston
44°N
44°N
WARD
NTE.
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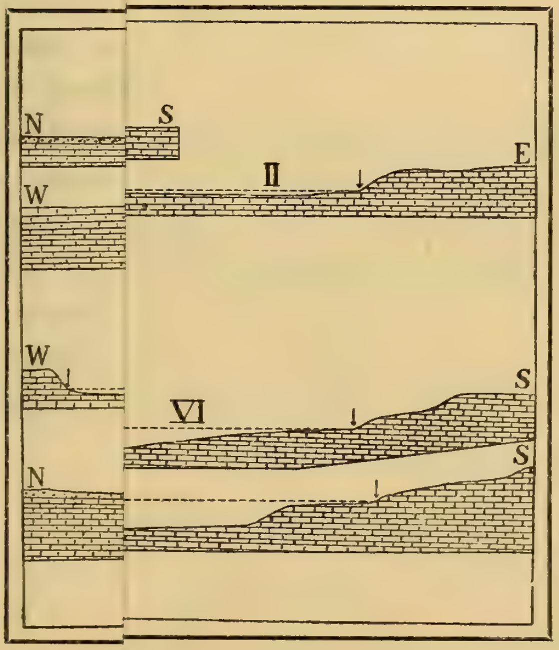
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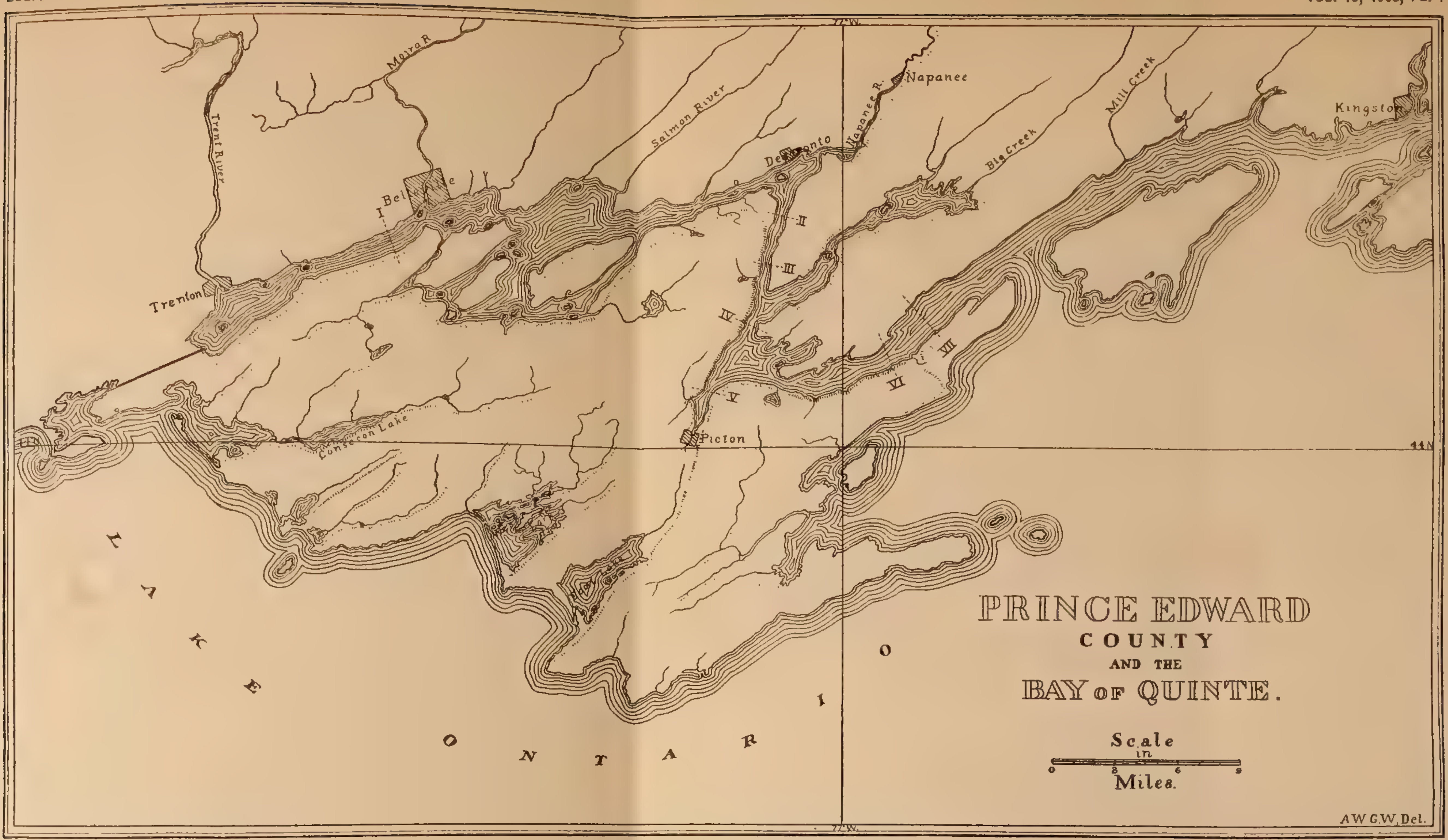
Moira R.
Trent River
Salmon River
Napanee R.
Napanee
Mill Creek
Big Creek
Kingston
Deseronto
Belleville
Trenton
Consecon Lake
Picton
I
II
III
IV
V
VI
VII
77°W.
44°N.
L A K E O N T A R I O
PRINCE EDWARD COUNTY AND THE BAY OF QUINTE.
Scale in Miles.
0 3 6 9
A.W.G.W. Del.

FIGURE 1.—PRINCE EDWARD COUNTY AND BAY OF QUINTE

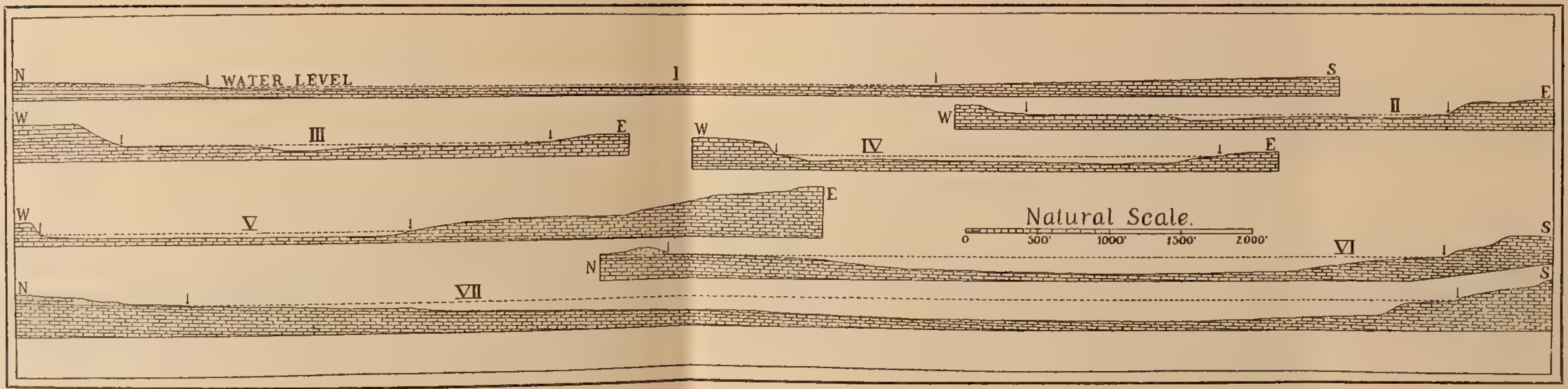
N
WATER LEVEL
I
S
W
II
E
III
IV
V
VI
VII
Natural Scale.
0 500' 1000' 1500' 2000'

FIGURE 2.—PROFILE SECTIONS ACROSS THE BAY OF QUINTE

MAP AND SECTIONS OF PRINCE EDWARD COUNTY AND BAY OF QUINTE

Moira lake, just south of Madoc village being an expansion of the river on the inner lowland. It enters the cuesta below Stoco lake (also on the inner lowland) in a valley of the first type, follows this valley for about 8 miles, until displaced by morainic deposits near Thomasburg, whence it flows in a new channel cut in drift until it is joined by an important tributary from the northeast near Plainfield. This tributary in part of its course, and in all probability in all of it, occupies one of the old rock valleys. The united streams continue in the course of the old valley to Foxboro, where they turn south and flow with numerous rapids through a new channel in a straight consequent course to the bay of Quinte at Belleville.

The eastern portion of the Trenton-Desoronto division is more complex, and it is necessary first to refer to the most important tributary stream, the Salmon river. This stream enters the limestone escarpment from Beaver lake, the latter lying on the inner lowland near Tamworth. The valley of the Salmon all the way across the limestone area is deep and, relatively to the valleys of the other streams, narrow and very steep scarped, especially on the southeast side.

Running along the south shore of the bay from Green point opposite Desoronto to Northport, and thence southwest past Demorestville and Crofton and across Prince Edward county to the north of Consecon creek and lake, is a well defined cuesta. At Telegraph narrows, about 4 miles west of Desoronto, the bay is very shallow, and rock is exposed in numerous places on either side and forms islands in the bay. Telegraph narrows probably marks a local divide between waters which flowed in front of the cuesta eastward to join the valley of what is now the Napanee river and the Long reach, and westward in front of the cuesta along the general course now indicated by the direction of its crest. This valley was confluent with that of the Salmon river to the west of what is now Big island. This main valley was probably joined in the vicinity of what is now Wellers bay, on the west coast of Prince Edward county, by the stream which carved the valley now occupied by Consecon creek and lake. Several other minor valleys are also associated with the Salmon river valley, but in the absence of topographic maps it has not been possible to work out all the details as yet. The unsubmerged portions of the intervalley areas of these confluent valleys form the three large islands southeast of Rossmore.

Long reach and Napanee river.—The Napanee river rises on the Archean upland to the northeast of the Black River cuesta, and traverses the limestone region in a deeply incised valley, the rock scarps of which may be followed all the way across from the front of the cuesta to the bay of Quinte. The scarps on both sides along the upper portions of the valley, where it is narrow, are sharply defined and often precipitous. As it gradually broadens, that on the north side becomes less steep, the cliff features nearly disappear, so that in the vicinity of Desoronto it has an even slope to its summit. The scarp on the east side, retaining its steep cliff-like character, is continuous with the high scarps along the eastern side of the upper portion of the Long reach. From the vicinity of Desoronto the course of the old valley seems to have been toward the south, in a direction more nearly in accordance with the dip of the strata. As a result, we find the sides of this portion of the valley bounded by steep rock cliffs, that on the west, the highest, rising about 185 feet above the bottom of this section of the bay (plate 7, sections II–V). The scarp on the west side is the edge of the cuesta, on whose outer slope several of the minor streams of Prince Edward county take their rise. It runs from the vicinity of Green point, where it is continuous with the scarp before noted as lying to the south of the upper part of the bay of Quinte, to Picton, and thence southwest across the county, gradually losing its cliff character west of Picton and becoming an evenly graded slope.

Confluent with this consequent valley is another less broad, rock-scarped valley, the submerged portion of which now forms Hay bay. Hay Bay valley can be traced all the way across to the inner lowland, and Big creek drains a small area of the lowland through the escarpment to the bay.

To the south of the Twelve Mile reach is a high escarpment, rising near Glenora to 225 feet above bay-level and 308 feet above its bottom. This escarpment forms the east side of Picton bay and extends across Prince Edward county, with gradually decreasing elevation, to the south of East lake, being submerged beneath the waters of lake Ontario at Salmon point (plate 7, sections VI and VII). This escarpment is the south wall of a broad valley which joined the ancient Napanee valley from the east a few miles above Picton. The united streams crossed Prince Edward to East lake. The lower portion of this valley is now traversed by a sand bar thrown up by the waves of lake Ontario, and the submerged portion of the valley behind this bar forms East lake.

The south side of the Twelve Mile reach east of Glenora, where it reaches its maximum height, gradually diminishes in elevation above present lake-level. The depth of the water in the bay gradually increases, however, to a maximum of 230 feet half way between the west end of Amherst island and the main shore, so that the actual depth of the valley is fairly uniform. With one interruption, where a portion is submerged and past which it can very readily be traced by means of the soundings, the escarpment continues to the east end of Amherst island. Between Prince Edward county and Amherst island the channel which breaches the valley wall is 2 miles in width and has a maximum depth of 83 feet, the depth of the water in the valley being 230 feet. At present it has not been possible to determine satisfactorily whether this main valley, whose submerged portion forms the Twelve Mile reach, is to be considered as the southwest extension of the valley through which Collins creek traverses the limestone areas. The valley of Collins creek is one of the rock valleys of the first type running through the limestone region from the inner lowland. The lower submerged portion forms Collins bay. This valley and the Twelve Mile Reach valley are directly in line, and this suggests that they may be parts of the same ancient valley. On the other hand, the charts show the existence of a depression of considerable depth (106 feet below water-level) between the Brother islands and the main shore, suggesting that Collins creek may have here turned eastward to join the valley which forms the next section of the bay—a case of pre-Glacial stream capture. Another alternative is that the valley of the next section of the bay and the Twelve Mile Reach valley were continuous. On the other hand, the maximum depth of the submerged divide across the Lower gap (4½ miles wide) between Amherst island and Simcoe island is only 6 feet higher than the greatest depth in the adjacent part of the bay, the latter being 106 feet below present water-level. So far as known, the bottom in this locality is all rock, with but a very small amount of drift. As will be seen by a reference to the map, the Lower gap is a continuation of the Bateau channel east of Kingston (described below), and from the general field relations it seems best to interpret it as the lower, and hence wider, portion of this valley rather than to consider it as a breach in the side of a valley which might have been continuous from East lake to below Kingston.

Kingston section.—The next section of the bay heads on the Archean areas east of Kingston, and runs southwest as a narrow valley, with steep rock scarps on either side at its eastern end. Between Howe island and the mainland, where it is narrowest and the rock sides are steep, it is known as the Bateau channel. The valley walls rise to a considerable height, over 100 feet, above present water-level. The south side is interrupted in one place by a cross-channel between Howe island and Wolfe island. So far as the present soundings are concerned, the present line of deepest water turns through this channel from the upper portion of the bay. The general field relations, on the other hand, are very strongly in favor of considering that the portion of the bay north of Wolfe island is a direct continuation of the Bateau channel.

Tributary to the bay, Cataroqui creek enters from the north. It crosses the limestone area in a deep broad valley, carving a typical " shut-in " canyon in an Archean spur which crossed its path, and joins the bay near Kingston.

The north shore of the bay west of Kingston as far as the Long reach is throughout its course a gently graded rock slope, in marked contrast to the cliff front of the cuesta on the south side. Several minor streams, all in rock valleys of the second type, enter the bay between the Long reach and Collins bay.

Saint Lawrence section.—The American outlet channel of the Saint Lawrence river is also one of these submerged valleys. The south shore in its present attitude is bordered by a more or less graded scarp. Near Clayton a small stream flowing in a valley of the second type enters it from the southwest. The head of the valley is located in the narrow channel between the Archean ridge which forms Wells island and the main shore to the south. The north side of the American channel is less abrupt than the south. Along the eastern portion of Long island it is bordered by a low cliff scarp. From the crest of this scarp the rock rises inland with a gentle graded slope to an elevation of probably 50 feet above water-level, with somewhat higher points in several places.

The cross-channel between Howe island and the mainland to the east, joining the Bateau channel with the main river, is connected with a series of Archean valleys north of Grindstone and Wells islands. The north shore of the same channel north of Grindstone island is also Archean rock. The south shore of Howe island is obviously a partly submerged rock bluff, such as borders all the valleys. The north shore of Long island opposite is also bed-rock. It is quite probable that the channel between the two islands marks the valley of a stream confluent with that which carved the Bateau channel, and that the rather broadly open valley from the west end of Howe island to the Lower gap was the work of the two streams.

FAULT THEORY OF ORIGIN OF BAY OF QUINTE DEPRESSION

The very remarkable zigzag course that is taken by Trent river in its upper part, and the no less remarkable course of the bay of Quinte, would naturally suggest that these topographic features were due to extensive faulting, and that the escarpments were the edges of uplifted blocks. The writer made a careful search for indications of fault movement in the field, but was unable to find evidences of any such movement. On the contrary, it was found in every case, without exception, that the differences between the opposite sides of any of the complex of valleys was invariably such as could readily be explained by the relative attitudes of the plane of slope of the valley and the plane of dip of the rocks, and that there are but little differences in height between the opposite sides. This relation holds systematically throughout the whole region. Again, where the Napanee river enters the Black River cuesta (this is also true of all the others crossing the cuesta) the escarpments on either side are of equal height, and, so far as could be determined, of precisely the same rock (actual identification of individual beds made elsewhere was not attempted here). The escarpment on the southeast is perfectly continuous to the vicinity of the inlet of Hay bay, where it gradually lowers to water-level. Throughout its course it retains nearly the same character, the rocks dipping away from the cuesta front. The opposite side of the valley gradually assumes a more graded slope, and although the basset edges of the strata are exposed, the general slope is very much gentler in the vicinity of the bay of Quinte than it is farther inland. On the opposite side of the bay the corresponding part of the cuesta (west of the Long reach) exhibits features identical with the portion of the cuesta to the east of the Long reach. The slight difference in height between the western and eastern sides of the Long reach is apparently associated with the character and dip of the rocks.

The block-fault theory to account for the origin of the zigzag course of these valleys is regarded by the writer as at present untenable, because there is no known evidence in its support, and it is not necessary to assume it to explain the relations of the various valleys and escarpments. The limestone rocks throughout the whole region are extensively jointed. In a very few cases there has been a slight local movement along the joint planes. In no instance has the writer noted a displacement of over 6 inches in a vertical direction. The direction of the master joint fractures is intimately associated with the trend of all the master valleys, though the modern post-Glacial channels are independent of them. It is quite probable that they, to a large extent, controlled the direction of the drainage of the area subsequent to the peneplanation of the limestones. It is not improbable that much of the drainage was at first subterranean along the line of the master fractures. Indeed, in one instance (Perch creek) the present stream flows along a joint fracture underground for a distance of nearly a mile. The intimate relation between the jointing and the valley sides is well shown in the cliff front along the west side of the Long reach, where, when considered in detail, it is found that systematically the slight salients and reentrants of the cliff are the obtuse intersections of joint fissures. The distances between these local salients are remarkably uniform alongt he whole 9 miles of cliff, producing a scrolled appearance. These master joints with their associated valleys and the parallel systems of valleys of similar trend on the adjacent Archean areas are probably associated with an extensive system of faults of pre-Orodovician date.*

NOTES ON OTHER STREAMS TRIBUTARY TO LAKE ONTARIO FROM THE EAST

In all essential features the valleys of the southwest-flowing streams in New York state are similar to those in Ontario. To the south and west of Clayton, and southeast as far as Black river, there are large relatively flat areas, the intervalley uplands, with a very limited drift cover and frequent exposures of flat limestone rock. A number of small creeks head on the different parts of this upland and flow southwest, the valleys gradually becoming well defined as they grow wider and deeper. The partly submerged western portions of these valleys form the numerous inlets on the eastern shore of lake Ontario. Without a single exception, the islands off that coast are merely partly unsubmerged portions of the rock wall between two valleys. The valley of Three-mile creek extends for some distancc above the head of the present stream, and is well defined by a low rock scarp on either side, the valley lying below the level of the upland plain. The writer did not have the opportunity of ascertaining whether it extended completely across the limestone area.

The Chaumont river occupies a valley of the first type of those described above, although the present river does not come from the inner lowland. The head of the present stream lies in a flat limestone plain between bounding rock scarps. A couple of miles farther east another stream heads in the same valley and flows northeast. The lower portion of the valley is submerged to form Chaumont bay. A reference to the map (plate 8) would suggest that the former courses of the valley of Three-mile creek and Chaumont river were between point Peninsula and the mainland. In the field, however, it is found that it is extremely improbable that this was so, because rock exposures are found close together at or near water-level, even on the neck between the peninsula and the mainland. The earlier course of one of the streams may have been across this neck, because there is a well defined valley here, but the course of the pre-Glacial Chaumont river seems to have been to the south of the point Peninsula. Three Mile creek at one time probably flowed between the peninsula and the mainland, but at a later stage it appears to have joined the Chaumont river, possibly a case of local stream capture, the bottom of the valley of the creek, now submerged as Three-mile bay, being at a considerably lower level than the bottom of the sag in the rock surface at the neck of the Peninsula. The valleys of the smaller streams marked by Guffin bay were tributary to Chaumont

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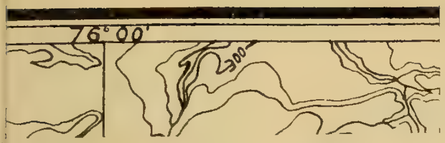
*This also has been suggested to the writer by Doctor Gilbert. It is proposed to discuss the problem in a later paper on the origin of roches montonné.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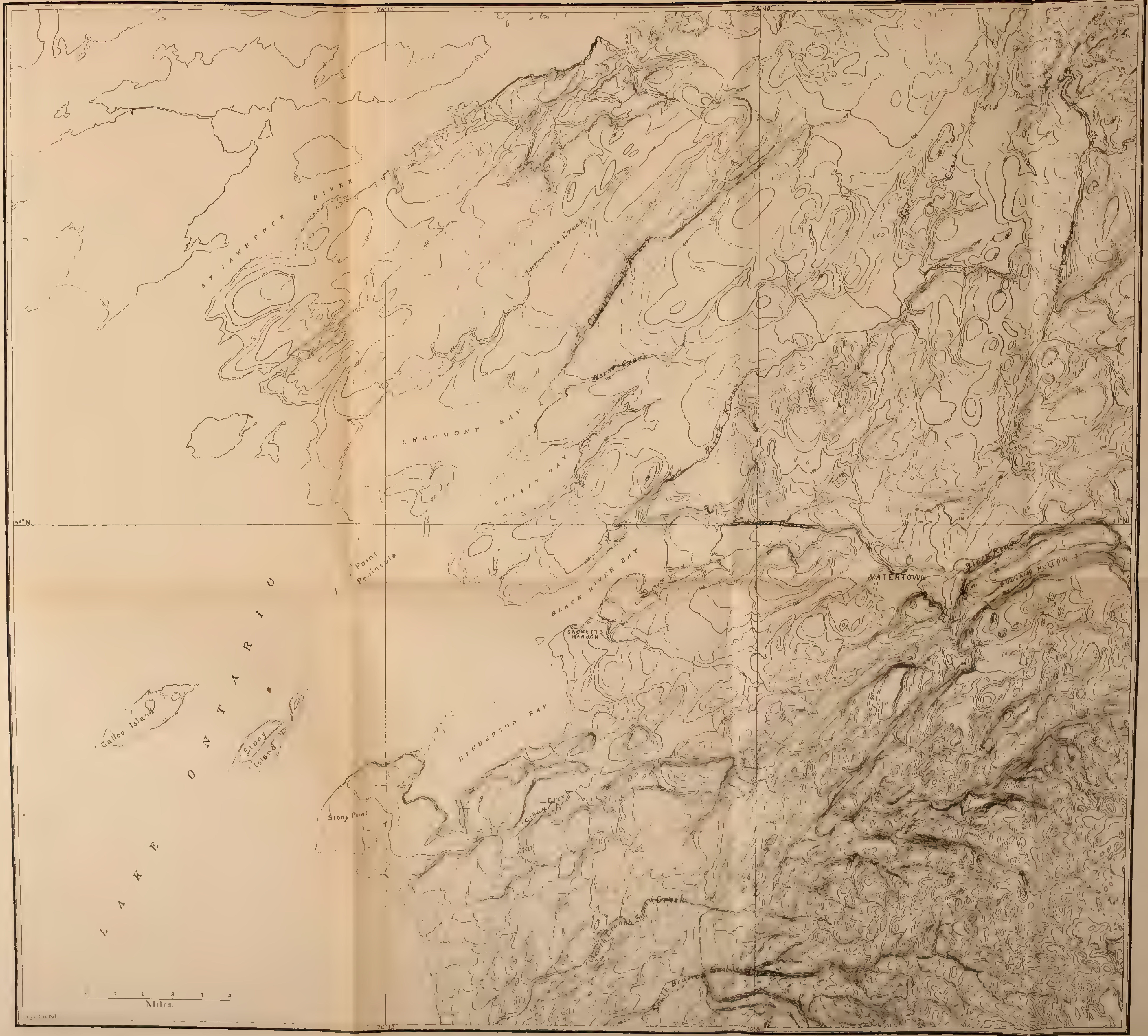
76°15'
76°00'
44° N.
ST LAWRENCE RIVER
Threemile Creek
Chaumont River
Horse Creek
Perch River
Indian River
CHAUMONT BAY
GUFFIN BAY
BLACK RIVER BAY
Black River
WATERTOWN
RUTLAND HOLLOW
SACKETTS HARBOR
Point Peninsula
HENDERSON BAY
Stony Creek
Stony Point
Galloo Island
Stony Island
LAKE ONTARIO
North Branch Sandy Creek
South Branch Sandy Creek
Miles
0 1 2 3 4 5

DISTRICT SOUTHEAST OF THE SAINT LAWRENCE OUTLET

Contour intervals, 20 feet

valley. From the soundings in this part of the lake, it is inferred that the ancient Chaumont valley was tributary to the ancient Black River valley which lies to the south of Stony island.

The next stream to the south is Perch creek. This stream rises near the Archean areas to the northwest of Theresa at Hyde lake. Under the local name of Hyde creek it flows across the Potsdam lowland in a well defined rock-scarped valley to Perch lake. This latter lake is located in a reentrant in the limestone cuesta. From Perch lake it flows southwest through the cuesta to Black River bay. About a mile below the village of Limerick, the present stream passes underground and follows a subterranean channel for nearly a mile. The older valley on top of the limestone is well defined, and judging from the bare character of the valley floor and the distribution of debris, at times of flood the present stream occasionally flows overground. At Limerick the present channel is a slightly sinuous rock gorge, about 50 feet in width and 20 in depth. In places the sides are locally rounded, though most of the gorge is cliffed. The general features of the gorge sides are such as to suggest that it is pre-Glacial, and that its form has been slightly modified by the ice. It is quite possible that the portion near Limerick is of glacial origin, owing to the down fracturing of the roof of the subterranean channel under the weight of superincumbent ice.

The largest and most important of the streams which cross the limestone areas to enter the eastern end of lake Ontario is Black river. The larger part of the catchment basin of this stream lies in the Adirondacks. The main stream flows along the inner lowland in front of the Paleozoic cuesta for many miles above Carthage, receiving a few short obsequent tributaries which run down the cuesta front. About 7 miles north of Carthage it turns abruptly and flows southwest toward Watertown. At Watertown the course changes a little to the north of west* and follows this direction to Black River bay. This bay is merely a partly submerged portion of the river valley. The course of the valley can readily be followed by the soundings to the southwest of Stony point, lying between the point and Stony island. The modern stream in its course across the limestone areas has cut out a rocky gorge in the bottom of the older flat-bottomed valley, and this gorge forms the present channel of the river. At Black river the gorge has a depth of about 40 feet. To the south of the old valley the walls are steep and often cliffed. To the east of Watertown and about a mile and a half from Black river is a very remarkable steep-sided rock valley called Rutland hollow, cut as it were on the side of the old Black River valley, since the upland to the south rises 313 feet above its bottom, and the bottom is 225 feet above Black river. This valley passes out toward the lowland to the northeast. Its southwest extension is occupied by Mill creek, and at one time the creek which occupied the Rutland hollow probably flowed outward in this direction. At a later stage in its history the headward growth of a small lateral affluent of Black river has intercepted the headwaters of the old stream by breaching the valley side. At the present time the drainage of the hollow is carried to Black river by this side stream, entering the river about a mile and a half east of Watertown.

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*A pre-Glacial modification not yet fully investigated, but evidently closely associated with the joint structure.

Just west of Watertown another small stream enters Black river from the northeast. Following up the valley of this we find that it is continuous with the valley of West creek, a northeast-flowing stream. The course of the valley is little obscured by drift, but the cliffed rock scarps a little higher on the west are to be seen near Evans mills. West creek enters Indian river just at the big bend, a mile northeast of Evans mills. The nose of the sharp spur around which Indian river bends is an Archean ridge. The amount of Archean rock now actually exposed is small, and the greater part of the point is underlain by a flat arenaceous limestone, marked as Potsdam on the geological map of New York state. The valley of Indian river, both above and below the bend, is deeply incised and has a broad flat bottom, the basset edges of the incised beds showing on the sides of the valley. A short distance above the bend and also a short distance below it (about a mile and a half), it has cut down to the Archean rocks. There is a strong probability that at one time there were here two streams, each flowing in a southwest direction along the edge between the sediments and the Archean rocks and confluent at what is now the bend. From this point the course of the confluent stream was southwest along the valley of West creek and thence to Black river.

South of Black river, Muskalonge creek, Mill creek, and several other streams flow in rock valleys more blocked by drift than are those north of Black river, but showing in general features all the characteristics of the unobstructed valleys to the north.

The Saint Lawrence Outlet

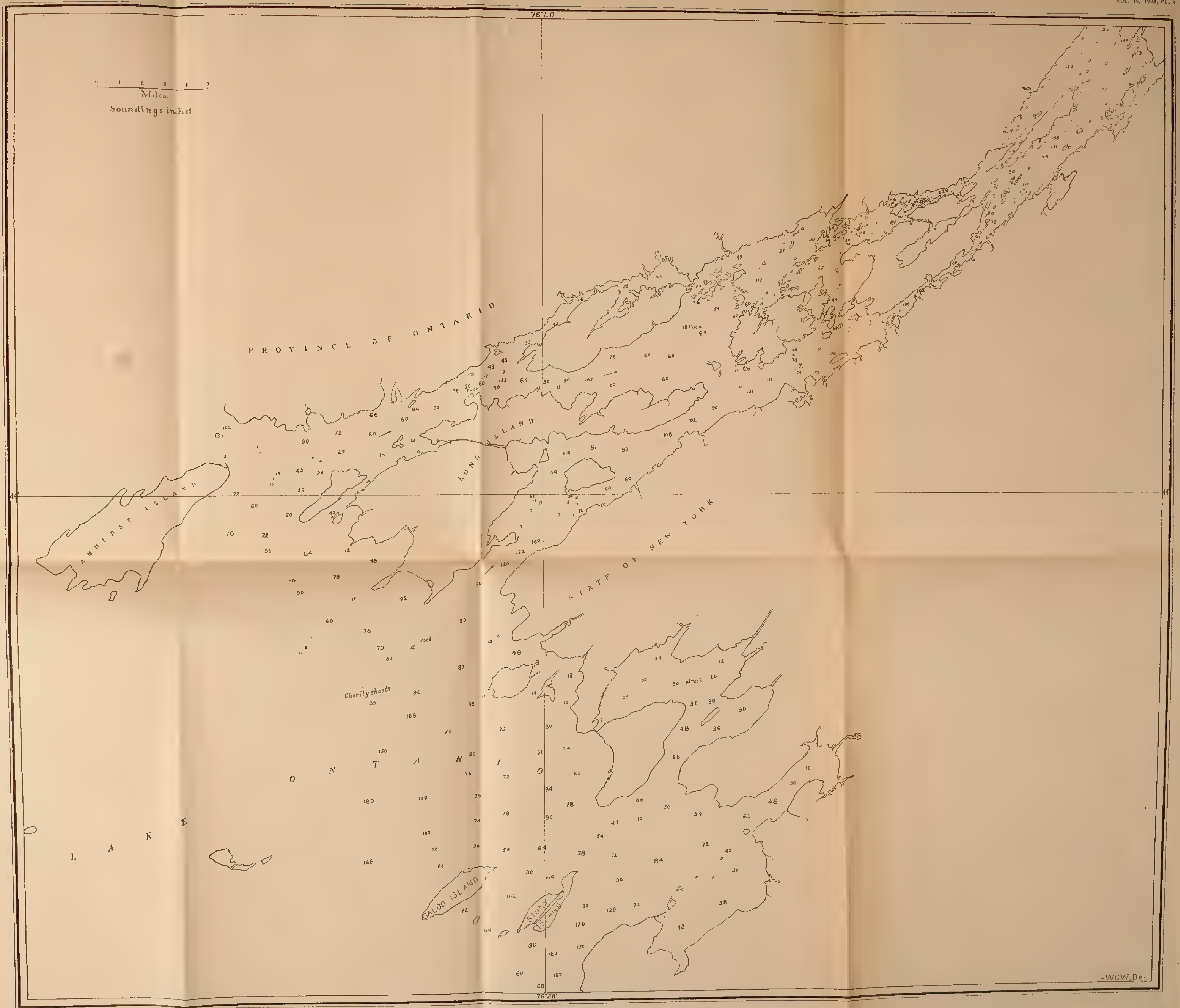
The water from lake Ontario passes into the Saint Lawrence by two main channels. One is through the Lower gap, near Kingston, and thence eastward, either to the north or to the south of Howe island. The other is between Wolfe island and the south shore. A section across the river near the west end of Howe island will cross three channels separated from one another by large limestone islands. Following each of these eastward to its lower end, if one considers the direction of water

movement, upper end if one considers the form of the channel valley, it is found that the valley gradually becomes narrower and shallower. The most northern, the Bateau channel, at its east end turns abruptly to the south to join the middle channel. Following the middle channel eastward, it is again found to narrow and become shallow rapidly ; to reach the main river it again turns to the right of its axial direction. The third or American channel narrows and shallows eastward as do the others. Between Wells island and the mainland its course is somewhat sinuous.

The western ends of each of the channels are submerged rock valleys of the first type here described. The islands between the channels mark unsubmerged portions of the valley sides. Each of these valleys and the ridges between them may be traced southwest for a considerable distance under the waters of lake Ontario (plate 9). The upper ends of each of the channels are located on the Archean belt. Each channel ends in a well defined valley between Archean ridges, partly submerged, it is true, but the ridges stand above water-level as the largest islands of the Thousand Island group. A study of the topographic features of the Thousand Island group shows that it is the characteristic semi-submerged Laurentian topography that is found in literally hundreds of other places throughout the Laurentian peneplain. We find the same succession of longitudinal valleys between ridges of Archean rocks, the axes of the ridges being parallel to the strike of the rocks, and the same series of shallower connecting straits across sags in the ridges. A reference to the map will show that an almost exactly similar system of longitudinal and cross-channels would be formed were the regions to the north of the present river submerged.

That each of the valleys with limestone sides become narrower eastward is due in part to the shape of the valley and in part to the fact that the highest point of the partly submerged Frontenac axis lies to the east of the eastern ends of the valleys.

From the foregoing descriptions and by reference to the accompanying maps, it will be seen that the outlet course of the Saint Lawrence river is not a well defined channel, but rather is a complicated series of channels. In fact, it is a series of partly submerged longitudinal basins, with cross-connections between the basins, the complex forming what is erroneously termed the channel of the Saint Lawrence. In reality the river has no channel of its own west of the Frontenac axis. East of the axis, in the lower parts of its course, it has cut a modern channel in drift deposits. The immaturity of parts of the channel east of the axis is shown also by the braided character of the stream. It is probable that east of the axis the course of the river is in part also of a compound character.


76°20'
Miles.
Soundings in Feet
PROVINCE OF ONTARIO
AMHERST ISLAND
LONG ISLAND
STATE OF NEW YORK
LAKE ONTARIO
Charity shoals
GALOO ISLAND
STONY ISLAND
rock
10 rock
14 rock
44°
76°20'
AWCW, Del.

SAINT LAWRENCE OUTLET

Typical soundings given in feet

The investigations as to the history of this portion of the stream are not yet sufficiently advanced to warrant extended discussion at this time.

SUMMARY AND CONCLUSIONS

In writing the foregoing description of the topography of the country bordering the east end of lake Ontario, it has been necessary to omit reference to many interesting minor details. In the majority of cases only those features which seem to bear directly on the question of the origin of the Saint Lawrence outlet, and on the problem of the origin of the principal features of the region, have been described and discussed. It remains but to summarize the results of the foregoing study.

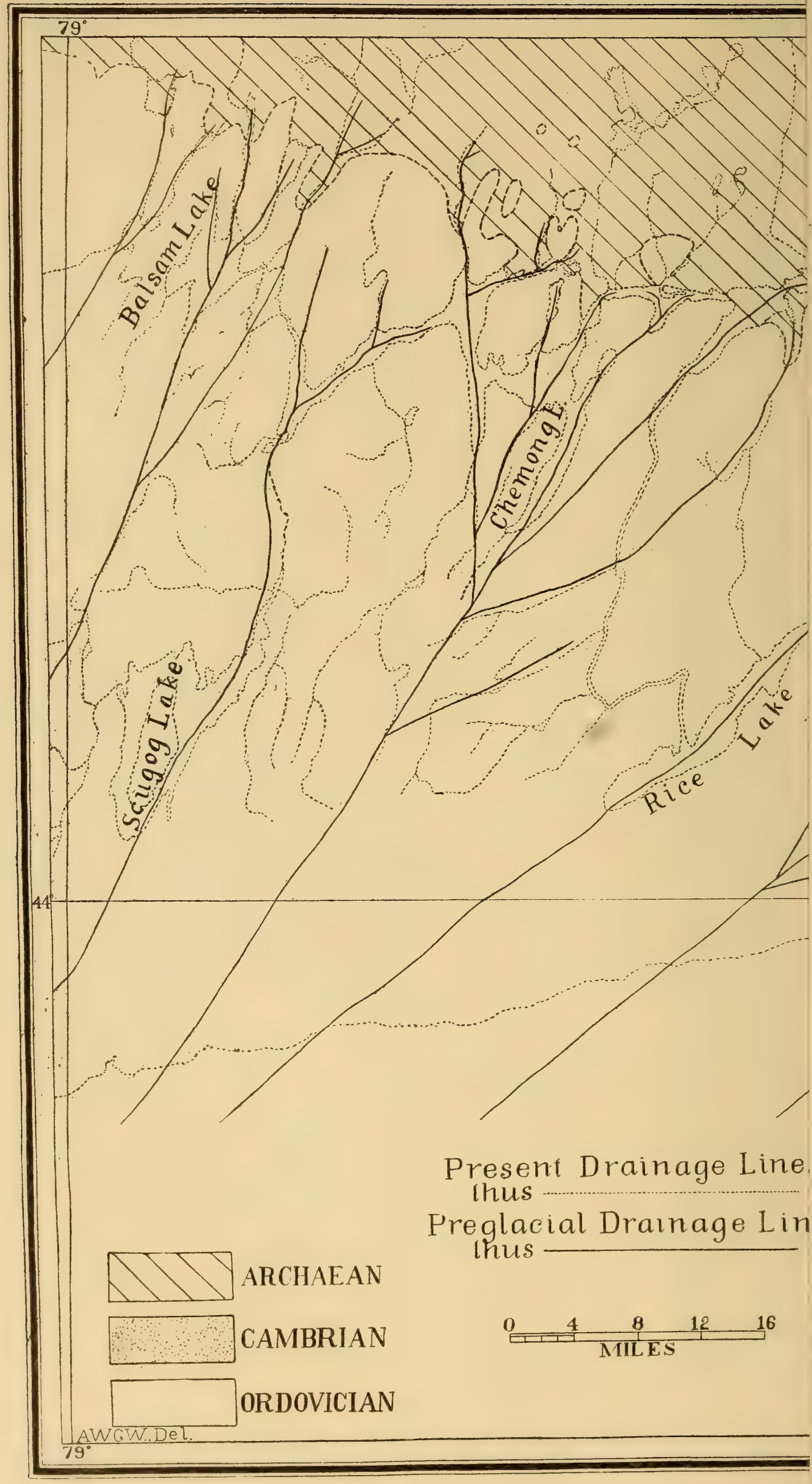
In the first place, the balance of evidence with regard to the amount of erosion by the ice-sheets which transgressed this region is distinctly in favor of the conclusion that this erosion was very slight. The main points on which this conclusion is based are:

1. The unquestioned fact that the ice-sheets which succeeded the earliest sheet whose till rests on the bed-rock overrode soft stratified and unstratified deposits which were the work directly or indirectly of the earlier ice-sheets, without materially altering the preexisting form, in so far as the evidence of the numerous cross-sections shows what that form may have been; from this it is inferred that there is little likelihood of the first sheet having been a more effective erosive agent.

2. The topographic features are similar to those produced by stream erosion in unglaciated regions, and bear no definite relation to the direction of the ice movement. On the contrary, their systematic development quite independently of that movement, accurate adjustments even to small details, and retention of characteristic forms show that the amount of erosion by the ice was very limited. They antedate the period of ice-transgression, at whose close the earliest till sheet was deposited, and by which the striations on the bed-rock beneath that till sheet were produced, as is evidenced by the occurrence of both the till and the striations in the valleys as well as on the uplands.

That the complicated system of valleys here described is due to stream erosion is inferred, as already stated, from their similarity in form and adjustments to valleys produced by stream erosion elsewhere in unglaciated regions. The direction of flow of the streams which carved them is inferred to have been southwest because uniformly throughout the system the valleys are found to become wider, frequently deeper, and always more mature in form as one proceeds from their heads on or near the inner lowland outward toward the region to which they now drain.

The main stream of the Trent River system is seen to alternately flow in a new channel of post-Glacial origin and in a course along an ancient


79°
Balsam Lake
Chemong L.
Scugog Lake
Rice Lake
44°
Present Drainage Line
thus
Preglacial Drainage Lin
thus
ARCHAEAN
CAMBRIAN
ORDOVICIAN
0
4
8
12
16
MILES
AWGW. Del.
79°

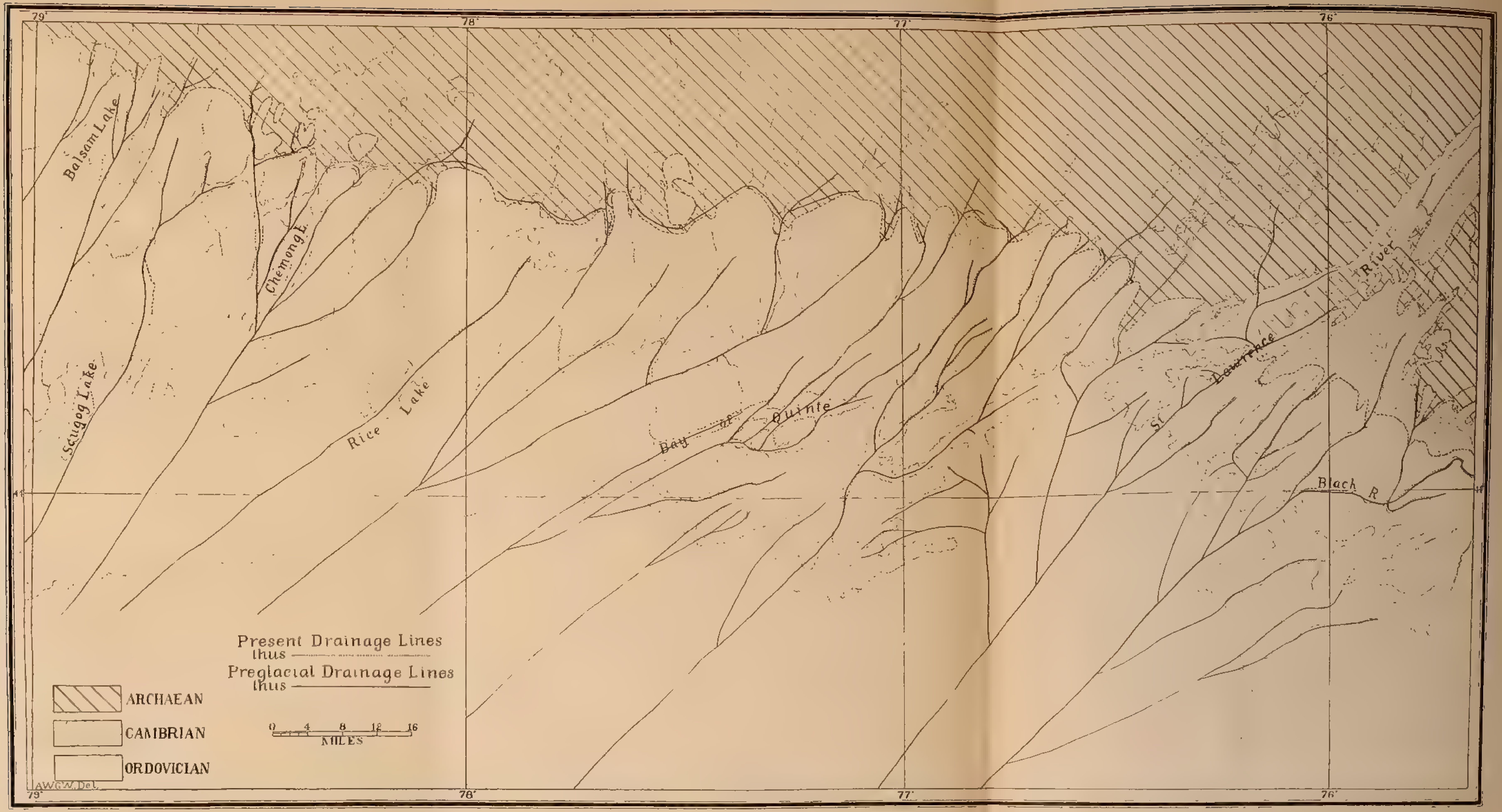
pre Glacial valley. The new channel almost always follows a direction consequent on the present attitude of the upland surface. This is strikingly shown in the long section of rapids between Lakefield and Peterboro (9 miles), in the section of rapids below Campbellford (5 miles), and in the section above Trenton (7 miles). A similar feature is shown by the Moira between Foxboro and Belleville.

In its course from the divide in central Haliburton to the bay of Quinte, the Trent passes through parts of 9 of these pre-Glacial valleys, and there are several others indirectly associated with it (plate 10). It should also be mentioned that there are several more of these valleys developed to the west of the Trent system, whose descriptions have been omitted from the present discussion. In every case there is sufficient rock exposed along the valley sides to show that their upper parts are carved in the rock. In many cases rock exposures are found along both sides of the valley throughout its length. In some cases, as in the Scugog valley, and in that of the western part of Rice lake, the existence of bed-rock directly associated with all parts of the valley is unproven; it is found associated with the northeast end of each valley, however. But even here the nature of the slopes of the valley sides and the fact that they are uniformly continuous with the part where the rock does occur make it extremely probable that it is not far below the surface, even where the existence of rock sides has not yet been proved. Again, it would be extremely improbable that without the existence of some such predisposing cause, the drift deposits would always happen to have been deposited in such a systematic position with reference to the rock-sided upper portion of the valley as to always extend it in an appropriate direction and with accordant grades.

The southwest extensions of all these valleys, north and west of Trenton, are blocked by the heavy morainic deposits of Central Ontario. The result is that in their present attitude their lowest parts form the basins of an extensive chain of small lakes. The new channels of the Trent river mark merely the lowest edges of the rims of each of these basins, the river spilling over this rim to the next adjacent valley at a little lower level.

The portion of the Trent system at lake-level, the bay of Quinte, is seen to consist of a complex of at least 7 of these ancient valleys, partly submerged, so that the details of the adjustments and interrelations between the various members can not always be satisfactorily determined. The unsubmerged parts of the bay of Quinte system of valleys are all occupied by streams tributary to the bay. In Prince Edward county a similar system of rock-sided valleys has been developed with minor north-facing cuestas, only in part associated with the Trent system.

In New York also it is found that valleys similar in every respect to


79°
78°
77°
76°
44°
Balsam Lake
Chemong L.
Scugog Lake
Rice Lake
Bay of Quinte
St. Lawrence River
Black R.
Present Drainage Lines thus
Preglacial Drainage Lines thus
ARCHAEAN
CAMBRIAN
ORDOVICIAN
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AWGW. Del.

PREGLACIAL DRAINAGE OF AREA AROUND NORTHEAST END OF LAKE ONTARIO

those north of the lake have been developed on the bed-rock, and these still preserve all the essential features of valleys produced by river erosion.

The so-called outlet channel of the Saint Lawrence river is in reality a complex of three partly submerged valleys similar to the bay of Quinte. The portion of the Saint Lawrence in the vicinity of the Thousand islands is merely a series of longitudinal basins with connecting straits across sags in the interbasin ridges. No definite channel exists. The topography is similar to that characteristic of partly submerged Laurentian areas found in many places over the great Laurentian peneplain.

The courses of the rock valleys associated with the Saint Lawrence outlet and of the rock valleys of New York to the south of the river may be traced for a considerable distance on the bed of lake Ontario by means of the soundings.

The water of the Saint Lawrence system passes eastward at the present time over the lowest part of the Frontenac axis. The existence of the sag over which the river passes is probably due to local differential depression. The direction of flow of the water west of the submerged divide on the axis is opposite to that in which the water flowed when the valleys were carved in the limestone area. East of the divide on the axis the direction of flow is probably as it was in pre-Glacial times.

At a time prior to the existence of lake Ontario the valleys forming the Saint Lawrence outlet, all the valleys of that part of New York east of lake Ontario, the valleys of the Bay of Quinte section of the Trent system, and the valleys of Prince Edward county formed part of a river system now dismembered.

Finally, it may be suggested that the maturity of form, the size, and the course toward the deepest part of lake Ontario suggest that the pre-Glacial Black river was the master stream of the system. Its course and position with reference to the Niagara cuesta suggest that it was a master subsequent stream flowing in front of the cuesta westward. Probably some of the streams in the valleys forming the lakes on the upper part of the Trent system were tributary to this master subsequent stream either directly or in a few cases after confluence with each other.

As has been pointed out by Grabau * and the writer † independently, this master subsequent was probably joined by a second master subsequent from the north, flowing south in front of the Niagara cuesta, the two subsequents being confluent in the vicinity of the depression whose submerged portion forms Burlington bay, at Hamilton, Ontario; thence they probably followed the course of an initial consequent stream through the Niagara cuesta via the Dundas valley to the Erie lowland.

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*A. W. Grabau: Guide to the Geology and Paleontology of Niagara Falls and Vicinity. N. Y. State Museum Bulletin, xlv, 1901.

†Physical Geology of Central Ontario. Trans. Can. Inst., vol. vii, 1901, p. 181.

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GEOLOGY UNDER THE PLANETESIMAL HYPOTHESIS OF EARTH-ORIGIN

BY HERMAN LE ROY FAIRCHILD

(*Read before the Society January 1, 1904*)

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INTRODUCTION

The nebular hypothesis was not a scientific induction, but cosmic philosophy. Propounded by Swedenborg and Kant, it was given mathe-

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By special action of the Society, a preliminary edition of 300 copies of this paper was printed without covers on January 30, 1904, under the title, "Geology under the new hypothesis of earth-origin," and distributed to members of the Society for discussion. The pagination, from 1 to 20, was on the center of the bottom of the page. The discussion resulting therefrom has been appended to this paper. Communications or portions of communications which discussed the planetesimal hypothesis are not included here, as the paper is not a treatise on that hypothesis, but only on its geologic bearings.—EDITOR.

matical form by Laplace in a tentative way. It has been called the grandest conception of the human mind, and, for the eighteenth century, it might have been regarded as good science. It fails, however, to meet the requirements of a modern scientific hypothesis because it does not explain all the facts. But in the absence of any rival theory it has held possession of the field, and has been more generally accepted on insufficient basis than any other conception in scientific philosophy. The time has come for judgment and probable condemnation of the old hypothesis. The formulation of a new and better hypothesis by an honored Fellow and former President of this Society will be recognized in the future as opening a new epoch in earth science and as one of the glories of American geology. This is true even if the new hypothesis should not wholly stand.

The critical application of accepted principles of physics to the nebular hypothesis, by Professor Chamberlin, has revealed its weakness. The planetesimal hypothesis which he has formulated as a substitute seems to explain much better both the astronomical and geological phenomena. It may not be immediately and universally accepted, as it destroys the present foundation of many geophysical theories and because the leaders in science are committed to the old ideas; and in all its claims it may not be true, but its main postulate, that the globe was formed by accretion of cold matter, will probably stand.

The purpose of this writing is not to make an extended argument for the new hypothesis * nor to discuss its relations to celestial physics, nor even to the solar system, but to indicate its bearings on several problems in geology and very briefly to show how these problems are simplified by the new conception. It is predicted that under the stimulus of the new thought so many changes will be made in our views of geologic processes that the science of geology will be rejuvenated, as its theoretic or philosophic advance has been seriously retarded by its dependence on a false conception of earth genesis.

Comparison of the Nebular and Planetesimal Hypotheses

The old hypothesis assumes the existence of a mass of incandescent vapor, with or without a nucleus, which by condensation and rotation was differentiated into successive rings, the latter being eventually gathered into the planets while still retaining intense heat. From this postulate there necessarily follows the conception of a cooling earth, and hypogeic geology has been founded on the idea of crustal solidification on a molten globe. The new hypothesis holds that the disseminated planet-forming matter had lost its heat while yet existing in the loose form, as rings or zones or wisps of the parent nebula, and that the glob-

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* The full exposition of this hypothesis will be found in a new text-book of geology by T. C. Chamberlin and R. D. Salisbury.

ular planets were formed by the slow accretion or infalling of cold, discrete bodies or particles ("planetesimals").

The old hypothesis assumes an originally hot globe with shrinking on account of cooling. The new regards the globe as originally and always cold at the surface, and the interior heat as the product of gravitational condensation. The old view requires continuous cooling of the globe, while the new allows the conception of increasing internal heat. The old hypothesis makes the earth of largest size at birth and of constantly diminishing volume. The new regards the earth as beginning with a small nucleus and slowly growing by surface accretion, but with large reduction of volume by compression during and subsequent to the accretionary process. The old hypothesis involves the recognition of a primal, heated atmosphere and ocean consisting of the more volatile substances of the earth's mass. The new derives the present fluid envelopes from the earth's interior by a slow process of expulsion due to pressure and heat.

The above brief contrast between the gaseous and the planetesimal hypotheses could be extended, but this will be sufficient to show how fundamentally opposed they are in their application to the origin of the globe. The bearing of the new hypothesis on a number of topics in physical geology will now be very briefly discussed.

ORIGIN OF THE ATMOSPHERE

The nebular or gaseous hypothesis requires that the heated globe should be wrapped in the lighter and more volatile substances. The atmosphere and hydrosphere are thereby made coeval with the globe itself. The fluid envelopes must have primarily contained under high temperatures more or less material which was later given up to the lithosphere. Speculation has been indulged concerning the hypothetical deposits formed by precipitation from the cooling waters, but no rocks which can be referred to such genesis have ever been found. According to this conception, the air and the sea are only the residue of the primeval envelopes, although it has been recognized that even under present geologic conditions there is interaction between the lithosphere and its fluid envelopes, with some exchange of material. For example, it seems impossible, under the view stated above, to escape the conclusion that all the carbon dioxide of the present atmosphere, along with that now stored in the rock strata, must have been originally held in the volatile envelopes. The difficulties in the way of harmonizing geological facts with this conception have long been recognized by geologists, but have been reserved for future solution.

The new hypothesis claims that the substance of the atmosphere and ocean were originally a part of the planetesimals and helped to form the earth's mass. Whether the elements were superficial condensations on the solid planetesimals, like the occluded gases of meteorites, or formed part of their essential substance may not be important to the present discussion. The really important principle is that these substances were world-stuff, and that they were carried into the earth's mass by the accreting process of earth-making. A large portion of the nitrogen, oxygen, hydrogen, carbon, helium, argon, and other substances has been subsequently forced from the earth's interior to the surface by gravitational condensation and the resulting heat. This out-squeezing of the volatile substances has been a continuous process ever since an early stage of earth accretion. But the atmosphere did not exist until the earth had reached a size somewhat larger than the moon, for it appears, according to the laws of kinetics, and judging from the present naked condition of the moon, that up to that size the gravitational attraction of the earth was not competent to hold the gases on its surface. Even today the molecular velocities of hydrogen and helium seem to be sufficient to carry the molecules of those gases beyond the earth's efficient attraction. The atmosphere and the ocean of today are only such portions of the gaseous emanations from the earth's interior as the earth has been able to hold within its grasp, minus the considerable part which has been restored to the superficial lithosphere by carbonation and oxidation processes.

The atmosphere has had a slow growth, from a probable film of carbon dioxide to its present volume, and the growth is still in progress through volcanic and other exudations and by release of gases in decay of the crystalline rocks. Throughout geologic time, as recorded in the stratified rocks, loss and supply of the carbon dioxide seem to have been fairly well balanced, as Professor Chamberlin and other writers have shown how counterbalancing activities have probably served to check great excess of this chemically active substance on the one hand or its great depletion on the other and how the ocean has acted as a reservoir and equalizer. In the case of nitrogen, there would seem to have been little loss on account of its chemical inertness. The relative proportion of oxygen is an interesting question. The suggestion of several writers, including Lord Kelvin, that the presence of free oxygen in the air is due to the action of sunlight on plants, is opposed by the requirement in oxygen of the earliest animal life. The relative intensity of oxidation processes in early as compared with later geologic periods is a new problem under the new hypothesis. Such knowledge as we have relating to geologic climates seems to indicate that the atmospheric conditions of post-Archean time were not radically unlike those of today. But the primitive atmosphere must have been very different, as, theoretically, it consisted of the gases of lower molecular velocities. The carbon dioxide seems to have been the first of the atmospheric constituents to be retained on the surface of the growing globe. The enlargement of the earth and of its attractive power added the lighter gases to its envelope, and the carbon dioxide has been relegated to a minor place in volume. The active consumption of the gas in carbonation of the crystalline rocks has been a positive reduction of vast amount. The nitrogen has suffered little loss, on account of its inertness, and has become the preponderating element. The amount of water exhaled by the earth has been immense, but it has been mostly condensed to liquid, and has always been a small constituent of the atmosphere and locally variable, depending on temperature. It could not freely escape beyond the earth's control, because of its easy condensation to a liquid. The quantity of water seems to vary proportionally with the carbon dioxide, as the latter is an independent controlling factor of the atmospheric temperature. This matter will be discussed later under climate. Hydrogen and helium have never been important constituents of the atmosphere because their high molecular velocities have probably carried them beyond the earth's control, although it may be possible that free hydrogen in the air unites with oxygen or other elements.

Under the new hypothesis the atmosphere becomes a subject of geology. Its origin and its history, as well as its present constitution, are subjects not merely of speculation, but of geologic investigation, and the branch of geology called "atmospheric" will have a much broader field than merely rock-weathering and wind deposits.

Origin of the Ocean

Like the atmosphere, the hydrosphere is volatile matter pressed out from the lithosphere, and the ocean-making process is still active. In volcanism we see today one conspicuous method by which water is transferred from the interior to the surface of the globe. The existence of water in the earth's interior, even in the quartz of the crystalline rocks, has not been sufficiently emphasized. It is not necessary to assume that all the contained water exists as such in the deeps of the earth, as it may be produced in part in the superficial zone by union of the elements or by chemical reaction. Perhaps Siemens was right in his conclusion that large quantities of free hydrogen, or hydrogen compounds, from the earth's magma are explosively oxidized in the volcanic chimneys.

The seas could not form until the atmosphere had accumulated sufficiently to hold sun heat that would give the earth a surface temperature above the freezing point. Below this temperature the water which was forced from the earth's interior must have frozen in or on the cold surface of the globe. It would seem as if there must have been a long stage of conflict between the interior heat and the superficial cold. In the early stages of the growing globe the water was forced toward the surface only to be buried under the infalling material of world-growth. Subsequently the pressure and rising temperature forced it further surfaceward. This idea implies that much of the deeper interior may be comparatively dehydrated, which may help to explain the anhydrous state of vast outflows of molten rock.

It is probable that the moon now represents the pre-atmospheric stage of world-growth. Under the old hypothesis, the moon is supposed to have absorbed its fluid envelopes by interior cooling and resulting porosity, and the earth to be destined for the same fate, on the assumption that the amount of water on the earth is diminishing and the amount in the earth is increasing. The new hypothesis holds just the opposite view. The moon, under the new view, is not an illustration of a globe in old age or of completed evolution, but is an example of arrested development. The moon's growth was stopped by lack of building material before its gravitational power was competent to hold an atmosphere. Its internal heat was apparently sufficient and its volcanic action pronounced, but its gaseous exudations seem to have been lost into space or frozen at the surface. If the planetesimal hypothesis be true in its postulate of world origin and growth, then in the moon we may have a visible illustration of an early stage in the process.

The mineral contents of sea water are held by the old hypothesis to be derived from decay of primitive rocks, except to whatever extent they were indigenous to the nebulous envelopes. The new hypothesis allows derivation in part from superficial rock alteration, specially the carbonates, but suggests emphatically that most of the saline mineral content of the ocean has been derived, like the ocean itself, from subterranean sources.

EARLIEST SEDIMENTARY ROCKS

Under the conception of a globe cooling from a superheated state, the conclusion seems inevitable that the first deposits should have been chemical precipitates from the ocean of hot water. This idea has been the subject of speculative writing, but no rocks have been found which appear to have had such genesis, although, if such precipitates were ever formed, they should be discovered somewhere in recognizable form. The conception has been barren of results in petrography.

The nebular hypothesis requires that the globe should have been fully formed before the surface or epigene agencies began their work, and that all the vast deposits of fragmental origin, the clastic rocks, have been wholly derived from the primitive land areas by rock destruction. The new hypothesis allows a different view.

> "According to this, the ocean began its work long before the earth and moon had attained full size by gathering to themselves all the particles of the earth-moon ring or zone. Consequently there were oceanic sediments which were not wholly detrital, but were primitive world-stuff. The earlier ocean sediments must have been deeply buried under the later, and may now constitute part of the interior mass of the globe. It may be that the globe had attained full size before any of the visible clastic rocks were made. With the water on the earth's surface increasing by supplies from the interior and with matter still being gathered in from the exterior, the depressions of the primitive continents were more or less filled by a mixed class of sediments partly formed from clastic material, partly from volcanic, and partly from the material of incoming planetesimals. Encroachments of the ocean on the continents probably occurred as in later times, followed by withdrawals as the ocean basins sank and increased their capacity. As the decomposition of the clastic material was probably less complete than in later times, from lack of vegetal covering and other causes, the mixed sediments when metamorphosed resembled original igneous rock, and it is now difficult to distinguish the metamorphosed clastics from true igneous rocks."*

With the passing of the old hypothesis, it will be desirable to change the terminology of the rocks as far as this now implies an original molten or "igneous" state of the earth. Some new name will be desirable for the sediments which were formed chiefly or wholly from the planetesimals (the cosmic matter) in the early seas of the growing globe. Let us call such deposits *cosmoclastics*, and the primitive massive rocks, the *cosmics*. The downward succession of the rocks would thus be, from unaltered clastics through altered clastics (metamorphics) to metamorphosed cosmoclastics; while beneath these, perhaps ever invisible, lie the altered cosmics, the primitive deposits.

The above theoretical succession of the strata, the slow upward gradation from primitive world-stuff into the differentiated secondary sediments, seems in better accord with our knowledge of the deep-seated rocks than the assumptions of the old hypothesis.

Volcanic Phenomena

The vast extrusions of molten rock over the earth's surface without explosive phenomena, and the intrusions into the superficial zone known as dikes, sills and laccoliths, may be in harmony with either hypothesis of world genesis, as the main factors seem to be great internal heat, potential fluidity, relief of pressure and hydrostatic equilibrium. However, under the old hypothesis, which favors homogeneity in the interior, it is difficult to see why an outflow of molten rock once begun should ever cease. But the new hypothesis is more favorable to limited liquidity, since it favors heterogeneity of the earth's mass and consequent local variation in temperature and melting point.

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*Quoted from Le Conte's Elements of Geology, 5th edition, p. 299.

The varied phenomena commonly known under the term "volcanism" are much better explained by the new hypothesis. It is evident that the explosive action in volcanoes is due to the expansive power of heated vapors, chiefly water. Under the old view the supply of water is from the hydrosphere, but the assumption that volcanic water is atmospheric is founded mainly in analogy and has little basis in observation or sound reason. We may admit that the water of thermal springs and geysers and perhaps of some fumaroles is meteoric, but the volcanic water is too large in quantity and apparently from too great depths to be derived from superficial sources. The amount of volcanic water is enormous. Fouqué determined that the amount of steam expelled from one of the numerous parasitic cones of Ætna was equal in 100 days to 462 million gallons of water. This equals 16 gallons for every square foot of a square mile, or a depth of 32 inches over that area. But the steam product of the single cone was probably not the one-thousandth part, perhaps not the one-ten-thousandth part, of the whole product of the volcano during that time.

The interstitial water of the rocks can not be sufficient to produce the vast accumulations localized in the volcanic reservoirs, and efficient circulation at great depths seems impossible. The capacity of molten magmas to absorb vapors has been used as an argument for the meteoric source of the water; but an objection is that before the water can reach the absorbing magma it must pass through a great thickness of moderately heated strata, where the repulsive force is great and the absorbing power is small or entirely wanting. The idea of supply through fissures, subterranean or oceanic conduits, in the face of the vastly superior and opposing hydrostatic pressure of the molten rock, is not worthy of consideration.

The presence of water and other gases in the crystalline and deep-seated rocks is a familiar fact to the petrographer, and the theory that the volcanic waters were indigenous to the earth's magma has in later years been held by several students of volcanism; for example, Scrope, Fisher, Reyer, Tschermak, and Stübel. Nearly ten years ago the view was emphasized before this Society by Doctor Lane,* but the repressive effect of the old hypothesis has prevented the full recognition of the truth and of its value. However, it has not been shown how, under the nebulous condition of the globe, the molten nucleus could obtain a grasp on its occluded gases.

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*A. C. Lane: "Geologic activity of the earth's originally absorbed gases." Bull. Geol. Soc. Am., vol. 5, pp. 259–280.

The new hypothesis simplifies the problem not only by making the volcanic water and the accompanying vapors indigenous to the earth's mass, but by giving a plausible explanation of how they came to be a part of the magma. Volcanoes are at once the outlets for relief of accumulated vapor pressure and a source of ocean and atmospheric supply. With the reduction in volume of steam and the lighter gases, the heavier and non-explosive gases become more evident, and then occur the later phenomena known as fumaroles, solfataras, soffioni, and mofettes. It may be that in the volcanic reservoirs the several vapors are arranged, as in the atmosphere, according to their specific gravity.

The existence of carbon dioxide springs (mofettes), such as the "Dog Grotto" near Naples and the "Valley of Death" in Java, are well explained under the new hypothesis. Under the old view the mofettes were compelled to derive their carbon supply from limestones and carbonaceous shales. The Dog Grotto, with its strong and continuous flow for some thousands of years, probably, would imply a subterranean limekiln of immense extent. Shales could not furnish the supply, as they are not sufficiently permeable. This topic will come up again in discussion of the hydrocarbons.

The chlorides and other haloid salts in volcanic emanations have been assumed to come from sea water or from marine sediments, where the sea had left them. The variety of gases in volcanic eruptions can not all be derived from meteoric water, and some of them are not contained in sea water. The abundant sulphur compounds have not been accounted for at all. The resemblance of the mineral contents of the sea to the volcanic products lies in the fact that the ocean is itself the product of volcanism. The old view has put the effect for the cause.

The existence of volcanoes remote from any water body, and in arid regions, is not a difficulty under the new hypothesis. The comparatively nonhydrous condition of the molten rock in many outpourings is not entirely clear, but it is less a difficulty under the new hypothesis, since this does not favor homogeneity in the earth's mass nor uniform distribution of the volatile matter. The possible comparative dehydration of the deep interior of the earth has already been noted. Moreover, there is, so it would seem, greater opportunity for localization or concentration of the volatile matter under the new than under the old hypothesis, because of greater porosity of the earth's mass.

The theory of primogenial water-substance and other vapors under the new hypothesis does not at once sweep away all the difficulties and mysteries of volcanism, but it gives a more rational philosophy of the matter and a good degree of unity to the phenomena. Let us who have been trained under the old hypothesis be on our guard in discussion of the new theories that our arguments or objections are not derived from or based on the old views. A new viewpoint is necessary to get the right perspective of the problems.

SOURCE OF THE HYDROCARBONS

It has already been said that under the old hypothesis not only the carbon dioxide now in the air but all the carbon stored in the stratified rocks must have been in the primal atmosphere. The withdrawal of the carbon from the air and the storing of it in limestone, coal, and petroleum was formerly regarded as a divine process of purification, thereby fitting the globe for habitation by man and at the same time providing him with fuel. Geologists have long recognized in that view a serious difficulty, for such immense quantities of carbon dioxide have been withdrawn from the air since the advent of air-breathing animals that it is doubtful if its full presence in the atmosphere at one time is consistent with aerial respiration. By far the larger part of the stored carbon is in post-Cambrian strata, and a large portion in post-Paleozoic strata. The amount of carbon fixed in the stratified rocks has been variously estimated at from 20,000 to 200,000 times the present content of the atmosphere. The geologic evidences as to climate and life in Paleozoic time are decidedly unfavorable to the idea of a densely carbonated atmosphere. This point will appear later in this paper.

Another serious difficulty under the old hypothesis is the accounting for the large deposits and localization of hydrocarbons and their association with volcanic phenomena. It seems probable that the carbon dioxide of limestones is atmospheric or immediately oceanic. (There may be doubt as to the organic origin of all limestones.) It seemed plausible that the hydrocarbons of shales were also organic. From this it was not a long step, though a false one, to the assumption that all the masses of bituminous substances, under whatever conditions found, had been derived from the shales or limestones, and were primarily organic. The organic origin of all the hydrocarbons has been generally accepted in some vague way; but in the application of the theory many difficulties have been met, and the literature of the subject teems with doubts, interrogations, and admissions of ignorance. A recent hypothesis holds that the carbon dioxide of volcanic association is produced by the action of meteoric water on imaginary metallic carbides in the earth's interior.

The facts and phenomena relating to the occurrence of the hydrocarbons, which have no good explanation under the old hypothesis, are given a rational and consistent explanation under the new. Like the substance of air and ocean, the material of the hydrocarbons is all primarily derived from the earth's interior and the great localizations of bituminous matter, specially in volcanic districts, are probably of immediate derivation from subterranean sources. A few of the facts which discredit the organic theory and confirm the volcanic theory may be marshaled as follows:

1. The occurrence of great quantities of graphite in ancient gneisses and in eruptive rocks.
2. The occurrence of liquid carbon dioxide in the crystalline rocks in notable quantities.
3. The general occurrence in great abundance of hydrogen and hydrogen compounds in volcanic emanations, the same being true of carbon dioxide.
4. The frequent occurrence of mofettes or carbon dioxide springs, with constant flow, prevailingly in volcanic regions. Enormous quantities of this gas are exhaled in some localities. The Death valley in Java and the Grotto del Cane near Naples have already been mentioned, and many other examples could be cited. Bischof estimated that the volume of carbon dioxide evolved in the Brohl Thal amounted to 5,000,000 cubic feet, or 300 tons, in one day.
5. The immense deposits with extreme localization of petroleum, as at Baku, and of asphaltum as in Pitch lake, in regions of volcanism.
6. The association of petroleum with heat and solfataric action, as in Louisiana, Texas, and California.
7. The occurrence of solid hydrocarbons, as gilsonite, ozocerite, and albertite, in vein systems like ore bodies, and reaching to great depths.
8. The capricious occurrence of gas and oil in all geologic horizons, and usually with no clue to their derivation.
9. The localization of oil or gas in strata which are otherwise barren in the same material, thus proving its foreign origin.
10. The failure to discover any rocks which have certainly lost a carbonaceous content.

Here are only ten counts in an indictment which could be extended. Doubtless there are hydrocarbon accumulations from organic sources. Like other natural products, their origin and history are complex; but if the organic theory applied truly to all the hydrocarbons it should explain the facts, while most certainly it does not; and the theory has been a hindrance to the study. It is time that geologists ceased to grope in the darkness of this inadequate theory. The volcanic theory seems to fairly explain the essential facts, and it should be placed on trial. The close association of hydrocarbon accumulations with volcanic phenomena is a very striking and important fact, although generally ignored. It illustrates the repressing effect of a wrong theory when once established.

It will be seen that under the new hypothesis the geologic processes are not made more simple, but instead are given greater complexity. The hypogene forces are brought into present intimate connection with the epigene agencies. In other words, to the complex processes operative on the surface of the globe, there is added a widely distributed and presently active volcanism. This added complexity is only what should be expected in the growth of any branch of earth science, even if not wholly welcome.

Genesis of metalliferous Deposits

The commonly accepted explanation for the deposition of most vein ores is by the work of heated ascending waters or other vapors. Under the old view the water is meteoric and is made to descend against the same forces that cause it to rise. The new view simplifies the process by regarding the vapors as originally resident within the depths of the earth, and seeking escape from the rising pressure and heat. The formation of ore bodies is to be regarded as a part of the general process of expulsion of the soluble and vaporizable materials from the earth's interior by heat and pressure.

Origin of Gypsum and Salt Deposits

The suggestions under this topic are offered tentatively and as illustrating the radically different viewpoint of the new geology.

The old theory holds that the sodium chloride has been produced as a secondary product, resulting from decay of sodium-bearing minerals and reaction with chlorides, except to the extent that it was contained in the primal vapory envelopes of the molten globe. The ocean is thus made the immediate source of all the sodium chloride, and the deposits of rock-salt are supposed to be produced directly by evaporation of sea water or derived indirectly from the ocean through diffusion in marine sediments and reconcentration in salt lakes.

Under the new hypothesis the salt and gypsum or their constituents are indigenous to the earth's mass, and at least in part are derived, like the ocean itself, from the interior of the earth. They are certainly contained in volcanic emanations, and doubtless may have the same source; but we may venture another step in our theorizing, and question whether some saline deposits may not be accumulated directly by the eruptive processes.

It is certain, being a matter of present observable process, that some salt and gypsum deposits are produced by evaporation of saline waters, and it is therefore a legitimate theory that all similar deposits have the same origin; but some salt deposits are so thick and pure and so localized that no satisfactory explanation has been given of the formative conditions under the evaporation process. The Stassfurt deposits are some 1,200 feet in depth, and the lowest beds hold 625 feet of pure salt. At Sperenberg, near Berlin, the deposits are said to have been pierced 4,200 feet without reaching their base. At Wieliczka the salt deposit is 4,600 feet thick. A mass of salt is described at Parajd, Transylvania, with length 7,550 feet, breadth 5,576 feet, and depth 590 feet. When we consider that 93 per cent of the volume of sea water must be evaporated in order to throw down the salt, it is difficult to imagine the physical conditions of either sea or lake which could precipitate such localized masses in such pure state. The remarkably deep and pure deposits at Petite Anse, in the Mississippi delta, are still unexplained.

Salt masses sometimes contain inclusions of hydrocarbons, hydrogen, carbon dioxide, and nitrogen, which strongly suggests the association found in volcanic emanations.

The aridity of climate necessary for the production of salt deposits by evaporation must be taken into the account, and salt masses are found in strata as far back as the Cambrian. This fact seems positively inconsistent with the factors of climate required by the old hypothesis, as will be noted later.

It may be possible wholly to explain the salt deposits under the evaporation theory, but if so it is time it were done. The delay and difficulty suggest the wisdom of trying a new line of attack.

Geologic Climates

While climatology is immediately a province of meteorology, under the new hypothesis, which we are favoring, not only the origin of the atmosphere, but its subsequent changes in composition, producing climatal variations, are due to geologic processes. The new geology involves a new meteorology. Instead of the highly carbonated atmosphere and tropical climate of early geologic time, according to the old hypothesis, with slow decarbonation and cooling, culminating in the refrigeration of the present day and pointing to a "final winter," we shall regard the past climatic conditions as not radically unlike those of the present. We shall recognize that throughout geologic time there have been such variations in climate, periods of cold and aridity, or of heat and moisture, as we know have occurred since the Middle Tertiary. The paleontologic evidence bearing on ancient climates need to be reviewed in the light of the new meteorology.

In this connection it should be stated, as an interesting matter of history, that the planetesimal hypothesis was developed by Professor Chamberlin as an outgrowth of his studies in glaciology. He found the best explanation of Pleistocene cold to lie in the quantitative variation of the atmospheric constituents. This led to the consideration of the origin of the atmosphere, which naturally involved the genesis of the earth as well as its fluid envelopes. It is a striking illustration of the unity of all earth science.

As the writings* of Professor Chamberlin have so fully discussed this subject the present writing will give only the brief statement necessary to the purpose of this paper.

Oxygen and nitrogen are transparent to "dark heat," while carbon dioxide and water vapor intercept and store it. The thermal properties of the atmosphere are chiefly due to this property of these two gases, which are least in quantity of the important constituents of the air, the carbon dioxide forming only one-three-thousandth part; but on account of their thermal potency and their small proportion of the atmospheric volume any variation in their quantity produces disproportionally large thermal effects. The amount of water vapor depends directly on temperature, so that this gas intensifies the effect. either way, produced by changes in the amount of carbon dioxide. Consequently we may regard the carbon dioxide as the climate maker, and the important question is with reference to the fact and the cause of its volumetric variation.

The probable derivation of this gas from the earth's interior has already been shown, and it may be assumed that the rate of supply is fairly uniform. The gas is withdrawn from the air by rock decay and organic accumulations and is stored in rock strata and the sea. It would seem that the consumption of the gas could not be so uniform as the supply. Broad land areas of crystalline rocks favor rock decay by carbonation and the depletion of the atmospheric carbon dioxide, while restriction of the land areas reduces the consumption and allows enrichment of the atmosphere. Many other modifying, and even opposing, factors exist, but in the long eras of interaction between atmosphere, rocks, and ocean there must have been established a fair compensating adjustment between removal and supply of the carbon dioxide, though not an exact balance. Any enrichment of the air in this gas gives the atmospheric blanket greater power to retain the sun heat and produces warmer and more uniform climate, with greater moisture. Depletion of the carbon dioxide makes the air more transparent to reflected heat, the blanket is thinner, the temperature falls, the moisture decreases, and areal or zonal differences of climate are intensified, because the obliquity of the sun's rays becomes a greater proportionate factor.

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*Articles by T. C. Chamberlin in the Journal of Geology, vol. 6, pp. 609-621; vol. 7, pp. 545-584, 667-685, 752-788.

Extreme and rapid climatic changes can not occur for the reason that causes act slowly, while effects lag, and counterbalancing factors as checks come into play. One of these checks is the ocean, which serves as a great reservoir of carbon dioxide, containing some eighteen times as much as the atmosphere. On depletion of the atmospheric carbon dioxide the ocean by diffusion gives up some of its supply, and thus helps to bring back the normal balance.

If this theory of climate be true, it will harmonize with geologic facts. Let us make a tentative application. The great land elevation and expansion, with mountain formation, of Tertiary time was accompanied, at least in the earlier periods, by warm climate even in the arctic region; but it was followed by Pleistocene glaciation. The very remarkable glaciation found in Permo-Carboniferous strata of middle and southern latitudes followed the land expansion of the later Paleozoic and the formation of the Carboniferous coals. These two series of events seem quite clear. If other epochs of glaciation are found, we may expect that they will have succeeded eras of broad expansion of new lands or other causes of carbon dioxide depletion. Seasons of aridity, with possible production of salinas, are also the effects of impoverishment of the atmosphere in carbon dioxide and moisture in less degree, perhaps, than required for glaciation; but aridity will usually accompany glaciation, since both classes of phenomena imply unequal distribution of precipitation. Prevailing red color of the rock strata may also indicate comparative aridity. Seasons of warmth and moisture, with luxuriant plant life, should be found to follow eras of transgression by the sea and quiescent conditions. Professor Chamberlin has shown how submergence of the continental borders favors limestone accumulations, which in turn causes enrichment of the ocean and air in carbon dioxide, since the limestone fixes only one equivalent of the carbon dioxide and releases one to the water from the bicarbonate held in solution. For example, the warm and probably moist climate so widespread in the mid-Carboniferous followed the long submergence and limestone-making of the Subcarboniferous; and that of the Tertiary succeeded the limestone deposition of the Mesozoic and Eocene.

If the salt deposits of the Cambrian and later time are evaporation products, then certainly the atmosphere of those early times did not contain the carbon dioxide which has been stored in the later strata. These two sets of facts, the vast quantities of stored carbon and the ancient salt deposits, are unreconcilable under the old hypothesis. The new hypothesis, on the other hand, gives a satisfactory explanation for both classes of phenomena.

GLACIATION

It is beyond the plan of this paper to discuss at length the phenomena of glaciation under the new hypothesis, since it has already been traversed by our leader in this field. Briefly it may be said that glaciation is not the remarkable and unusual phenomena it was once thought to be, but may have occurred even in early geologic time. The conditions, geologic and meteoric, requisite for glaciation do not seem to be extraordinary. Glaciation is essentially a local phenomenon—a fact which was not formerly appreciated. Cyclonic circulation of the atmosphere, which localizes and concentrates the precipitation, with just sufficient cold to produce snow instead of rain, may initiate a snow field, the perpetuation and extension of which is an ice body. A cause of general low temperature would seem to be the reduction in amount of atmospheric carbon dioxide. The extent and altitude of the land masses probably have an indirect influence by determining the great barometric areas and the paths of cyclonic storms. It is possible that the attitude of the earth toward the sun may have some effect, and that the precession of the equinoxes might, at a critical time, help to produce the alternation of glacial with interglacial epochs. It is probable that glaciation is not a simple effect, but the product of the interaction of several factors, atmospheric, geologic, geographic, and astronomic, and all these so delicately balanced that any slight change may cause great effects.

We are living in a glacial period. The waning glaciers of the Pleistocene are still found in every quarter of the globe; but within a generation the northern glaciers have shrunk in conspicuous degree, although the meteorologic data have given no certain hint of climatic change. It may be that decrease in snowfall is a greater factor in the shrinkage of the Alpine and Alaskan glaciers than increase of temperature, and it is probable that climatic changes which would be competent to produce a rapid growth of the existing glaciers might occur and yet be so imperceptible as to be undetermined by less than a century of accurate observation.

DIASTROPHIC MOVEMENTS

That mountain systems have been formed by lateral or tangential pressure and consequent crumpling of the strata is a fact of observation. The apparent cause of the mountain-making compression is shrinkage of the globe. Under the nebular hypothesis a difficulty is here met which has never been squarely faced, but, like so many other contradictions of facts by the old hypothesis, has been neglected in the hope that some time, somehow the explanation would be found. The amount of tangential compression which the physicists allow to the crust of the cooling globe is insufficient to account for the actual shortening which has occurred in the making of the many mountain systems. Mallet estimated that the earth had shrunk from the molten state 189 miles in diameter, a circumferential reduction of less than 600 miles, and most of this must have taken place during solidification and in the stages of high temperature. But nearly all the great existing mountain systems have been formed since later Paleozoic time, since which time the secular contraction must have been very small. Claypole estimated the amount of shortening in the Appalachians as 88 miles, and Heim estimates the same effect in the Alps as 72 miles.

Under the new hypothesis the earth shrinkage is due to original porosity and gravitational compression and is in active operation today. The amount of such spacial reduction has not been estimated, but it must be several times any possible reduction due to cooling. The ocean represents elimination of interstitial space; so does the atmosphere, condensed to solid or fluid, and also the unknown but enormous amount of gaseous material which has escaped from the earth's control. To the contraction represented by this vast amount of out-squeezed material must be added the condensation of the interior mass as absolute molecular compression, without extrusion of matter. This latter factor in the shrinkage of the globe is the only one which the old hypothesis can recognize.

The new view not only favors much greater amount of contraction in the globe, but makes the rate of contraction more uniform throughout geologic time.

To whatever degree the lateral compressive strain in the earth's surface layers may be due to insertion of wedges of igneous intrusives, the new hypothesis is as favorable as the old.

The up-and-down (epeirogenic) movements of continental areas are difficult of present explanation under either hypothesis. They would seem to have readier solution under the hypothesis which favors greater movement in the mass of the globe. The new hypothesis would also seem to be more favorable to changes produced by the invasion of the cold superior strata by heat from beneath, and the several possible requirements of viscosity, or mobility, or potential fluidity of the interior mass are equally well met by the new hypothesis.

With the passing of the discredited nebular hypothesis substitutes should be found for the misleading terms "crust," "nucleus," and "igneous."

IRREGULARITIES OF THE EARTH'S FIGURE

Although much has been written on the subject of continental forms, and even geometric and crystallographic principles have been applied, yet it must be admitted that no clear meaning has been found for the relief forms of our globe. Perhaps if the efforts had not been made under a false conception of earth genesis better results might have been attained. It seems likely that the relief forms are fortuitous, due to irregular accretion and unequal density, and that they have no genetic or structural relationship. This conclusion is strengthened when we consider that the configuration of the exposed lands is greatly changed by relatively small differences of vertical position, and even more important, by the almost certain fact that the disposition and relation of lands and sea have been in former ages radically unlike the present. This latter fact does not entirely contradict the principle of relative permanence of the continental and oceanic areas, but suggests that the principle must not be applied too rigidly.

Investigations seem to prove the unequal density of the earth, and the same conclusion is reached by physical deduction. The fact of epeirogenic oscillations and orogenic uplifts would seem to imply that under slowly applied and long continued forces the deeper rocks of the globe are viscous. This seems to require isostatic equilibrium, which in turn implies that the sub-oceanic portions of the lithosphere must be denser than the continental areas, and that the lithosphere of the southern or oceanic hemisphere must be denser than that of the northern or continental hemisphere. These conclusions as to the varying density of the earth may not be wholly contradictory to the nebular hypothesis, but they are certainly more favorable to the new hypothesis. Long duration of gaseous and liquid stages in the life of the globe would favor diffusion, convection, and resulting homogeneity. The new hypothesis, forming the globe from cold solid materials, favors heterogeneity, and is in better harmony with the geologic facts and the philosophic deductions relating to the earth's structure.

LIFE ON THE EARTH

Under the new hypothesis the problem of the origin and duration of life may be quite a different matter from the same problem under the old hypothesis. With the high temperatures required by the nebular hypothesis, life was at first impossible, and the low temperature of space has seemed to prohibit the importation of life germs from abroad. This placed a limit to both the origin and the duration of life on the planet. Recently the announcement has been made that the extremely low temperature of liquid hydrogen is not fatal to life germs. This being true, it is not inconceivable that germs might endure the cold of celestial spaces and might reach the earth by way of meteorites, or even that they might have existed on the planetesimals of the earth-moon zone or ring.

A much less speculative thought is this—that under the planetesimal hypothesis the ordinary conditions of temperature and moisture requisite for life as we know it were probably fulfilled long before the planet attained full size. The duration of life on the earth may thus be thrown far back in time, and the slow processes of biologic evolution are given far greater duration for their outworking. The limits of geologic time fixed by the physicists on the premise of a cooling globe have no application whatever under the new hypothesis, and the biologists and geologists are released from any time restrictions hitherto imposed.

Conclusion

The mathematical and physical speculations based on the conception of a cooling globe are unreliable and misleading. The recognition of this truth will release geology from its undue deference to authority. Geologists have not had sufficient confidence in the inductions of their own science, but have deferred too much to the philosophic deductions and speculations of the physicists and mathematicians. Scientific men in general seem to have an almost superstitious regard for mathematical results. The geologists have not properly realized that all such conclusions relating to geophysical problems, if based on assumed data and unknown conditions, are not entitled to any respect when they contradict observable phenomena or even sound geologic theory. For illustration: In the face of the abundant geologic evidence or argument for extreme age of the earth, geologists pare down their estimates because mathematical authorities figure out from hypothetical conditions and assumed data, based on the nebular hypothesis, that only a certain number of years can be allowed for the geologic history of the earth. Another example: Geologists neglect the formulation of a sound theory of the hydrocarbons because the prevailing ideas of earth origin require that they should be meteoric and organic. Geologists have been too generous in allowing other people to make their philosophy for them.

One of the characteristics of the new geology will be the greater and proper confidence with which its devotees will stand on the basis of their own observation and induction and decline to entertain hypotheses at variance with their own science. Another quality will be insistence on satisfactory theories for observed phenomena, instead of resting in old conceptions which do not explain or even may be in opposition to the facts. A difficulty in the past has been that physical geology has deferred to an hypothesis of earth genesis which was not good theory nor even a scientific induction, and which has been a hindrance and a burden on the progress of earth science.

The geology of the future will be made by geologists and not by the philosophers; and the study of planetary conditions will have one foundation in geology, as it is here that the science of worlds has an observational basis. The new geology is even today modifying the old astronomy. The student in cosmic science must have his feet on the earth even if his head is among the stars.

DISCUSSION

EDWARD H. KRAUS' COMMENTS

". . . the statement is made (page 255) that at present there is no satisfactory theory as to the formation of such salt deposits as are found at Stassfurt, Sperenberg, and elsewhere. From the various statements as to the 'physical conditions of sea or lake' and the 'aridity of climate' necessary, it would seem as though the so-called 'bar theory' of Ochsenius* had been entirely ignored. This theory was advanced as early as 1877, but it is only recently that we Americans† have come to appreciate that according to it neither 'aridity of climate' nor 'abnormal physical conditions of sea or lake' are necessary to explain such enormous deposits as occur at Stassfurt, etcetera.

"That there may be various deposits of salts, as, for example, the 'anhydrite region,' 'polyhalite region,' 'Kieserite region,' and also a 'Carnallite region,' likewise that from an ocean water of average composition it is possible to have more than twenty-five different minerals deposited, depending upon their solubility, and also their associates in solution. These and other facts are clearly and satisfactorily handled by the Ochsenius theory.‡

"It would seem that with such a satisfactory theory at our command, it is not necessary to question whether these large deposits 'may not be accumulated directly by the eruptive processes.'

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*O. Ochsenius: Die Bildung der Steinsalzlager und ihrer Mutterlaugensalze. Halle, 1877.

†J. F. Kemp: Handbook of Rocks, p. 78; also Hubbard in Geology of Michigan, vol. V, pt. ii, p. ix.

‡Brauns: Chemische Mineralogie. Leipzig, 1896, p. 340, etc.

" How by the ' eruptive process ' theory would it be possible to account for the fact that the calcium sulphate may at one time be deposited as anhydrite and at another as gypsum ; also that in some deposits we find the potash salts and others not ? "

[Even if we regard the " bar theory " as a good explanation of such complex deposits as those at Stassfurt, it is not wholly satisfactory as applied to deep deposits of *pure* salt, without sulfates and other chlorides.—H. L. F.]

WILLIS T. LEE'S COMMENTS

" In southern Colorado, extending from the mountains eastward, is a series of mesas capped with lava and bearing such relations to each other that they are undoubtedly remnants of a former plateau. The top of this plateau has the maximum elevation of 3,500 feet above the general level of the plain. The surface of the plain is traversed by numerous basalt dikes, the same material as that forming the mesa caps.

" In the vicinity of Folsom, New Mexico, south of the mesa, there has been extensive volcanic activity of recent date, and one small cinder cone of recent date has been found north of the mesa at Trinchera, Colorado. The volume of lava issuing from the Trinchera vent was very limited, and there are no dikes which are known to belong to the recent period of activity. Near the northern base of the mesa occur two dikes, each about three feet thick, running parallel. To all appearance they are members of the system of dikes representing the conduits through which the extensive mesa lavas flowed. It is possible, however, that they are of more recent origin, but this I can not state positively. If they belong to the older system, as seems probable, the rock now at the surface was formed prior to the removal by erosion of a thickness of about 3,000 feet. If they belong to the younger lavas, the configuration of the surface is such as to indicate that at least a few hundred feet of material have been lost from the surface since the dikes were formed. In either case a comparatively close texture would be expected for the dike material.

" On the contrary, the dike is scoriaceous and the cavities filled with petroleum. The oil is of a light amber color and moderately fluid. The quantity is such that when pieces of the rock are broken open the oil flows out in a small stream. Large pieces, which gave no external evidence of bearing oil, were found to be saturated throughout their mass. Small pieces of the rock, heated over a Bunsen burner, lost about 12 per cent of their weight.

" The large cavities, in some cases at least, were not connected. Cavities filled with oil were noted, surrounded by solid basalt one-fourth of an inch or more in thickness and, so far as could be observed, having no communication with other cavities. Certain pieces, when heated, allowed the oil to escape through pores; but others exploded violently when heated. It is difficult to account for the oil in this rock by any artificial means such as 'salting.' To satisfy my own mind on this point, however, I selected a place at some distance from the place where the oil rock had been found, and dug into the dike; oil-filled cavities were found as in the original place.

"The belief was entertained that the dike rock in some way picked up the oil as it passed through some oil-bearing stratum. A well was sunk between the two dikes to a depth of about 1,000 feet, but no oil was found. Drilling was stopped in the Dakota sandstone.

"It is somewhat singular that there should be cavities in the dike, and still more singular that these cavities should contain oil. There is no question that the oil is there, thoroughly sealed up in the basalt. Pieces of rock which were dry and weatherworn were found saturated with oil within. The oil seems to have been released only by decay of the rock. The well indicates beyond doubt that the oil does not owe its origin to deposits within 1,000 feet beneath the present surface. It is furthermore difficult to conceive of this oil using the basalt dikes as conduits rather than the porous sandstones of the Dakota and Benton formations which the dikes cut. It is equally difficult to conceive of fused basalt picking up petroleum from an oil-bearing formation through which it may have passed. It may be, however, that the pressure of 3,000 feet of rock, under some conditions, might keep the oil in a liquid state even in contact with fused basalt. On the assumption that the oil was of volcanic origin originally, as suggested by the new hypothesis, its occurrence in the basalt dike is not so strange as it otherwise appears."

ISRAEL C. RUSSELLS' COMMENTS

"*Oxygen in the air.*—On page 246 it is stated that the suggestion in reference to the free oxygen in the air being due to the action of sunlight on plants 'is opposed to the requirement in oxygen of the earliest animal life.' This objection seems to lack force, since the earliest animals, as we are seemingly justified in assuming, must have subsisted on plant food. The logic of events seems to require that algæ long preceded the appearance of animals on the earth, and did something in the way of supplying oxygen, as well as furnishing food for the earlier faunas.

"*Volcanoes.*—In the case of the parasitic cone on Etna, observed by Fouqué, cited on page 250, the evidence does not seem conclusive, so far as I have been able to learn, that the vent in question had a direct communication with the conduit of the main volcano. This question needs to be determined before the example cited can be admitted as evidence on either side, in reference to the source of the water-vapor of volcanoes. I am inclined to think that the secondary eruption referred to was a superficial phenomena, similar to the surface eruptions in beds of hot debris, recently observed on Martinique and Saint Vincent. If this suggestion should prove correct, the example referred to on Etna becomes just as strong an argument in favor of the meteoric source of supply of volcanic water as is now claimed for it by the opponents of that view. The quantitative measures of Fouqué seem to carry weight, but I doubt if the quantity of water mentioned is as great as was discharged into the air during a period of 100 days by any one of several superficial or 'debris craters' on Martinique or Saint Vincent during the earlier stage of the recent period of activity of the volcanoes on those islands.

". . ., on page 251, we are told: 'The variety of gases in volcanic eruptions can not all be derived from meteoric water, as some of them are not contained in sea water.' In the same paragraph, however, the statement is made that 'the ocean itself is the product of volcanism.' These two statements do not seem to harmonize; if the ocean is a product of volcanoes, why are not the products known to be given out by volcanoes found in the ocean.

"*Color of rocks and climate.*—On page 257 we read: 'Prevailing red color of the rock strata may also indicate comparative aridity.' This statement is a surprise to me, as I thought I had shown in Bulletin number 52, U. S. Geological Survey, and it has been conceded by several subsequent writers, that rock waste in regions having a warm climate is characterized by its red color—as, for example, the red residual soils of the southern Appalachian region, the *terra rossa* of southeastern Europe, etcetera—while the rock waste of regions having a warm, arid climate is characterized by a prevailing yellowish tone merging into gray—as, for example, in the arid region of the United States."

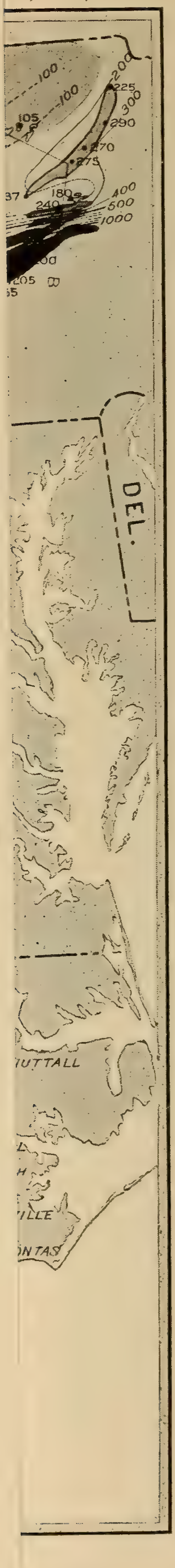
[The color of marine sediments and that of atmospheric rock waste are two quite different problems. The shales and sandstones of saliferous periods—for example, the Medina, Salina, Permian, and Trias—are characterized by red color.—H. L. F.]

"*Corrugated mountains.*—In speaking of the inadequacy of the contraction of the earth due to loss of heat, under the nebular hypothesis, to account for the formations of mountains of the Appalachian type, the essay before us fails to take account of another principle that must be conceded to have been in operation at the same time and to have influenced the corrugation of the earth's crust in a like manner. The phenomenon referred to is the transfer of matter through the action of volcanoes from below the earth's crust to the earth's surface. The volume of material thus withdrawn from the earth's interior, and consequently necessitating a crumpling of the earth's crust, is measurable in tens of millions of cubic miles (Van Hise), and is probably as important in leading to crustal deformation as any other agency that has been in action. The principle here referred to has been neglected by nearly all students of diastrophism."

FREDERICK W. SARDESON'S COMMENTS

The communication by Doctor Sardeson directs attention to his illustrated article published in the American Geologist, volume 26, page 388, 1900, and cited in volume 33, 1904, page 120, which tends to discredit the idea of a heavily carbonated atmosphere in early geologic time. Some fossil corals (Monticuliporoidea) which occur in the Ordovician have their branches twisted in a manner simulating heliotropism, thus indicating direct sunshine and not merely diffused light.

Doctor Sardeson says: "What is remarkable, further, is that the branches (of *Rhinidictya mutabilis* Ulr.) twist as they ascend, and turn the faces of the zoarium thus from east to west. This could be explained as due to influence of the sun's rays upon the zooids, those that were in the most favorable position growing a little the faster and crowding their neighbors, and the crowding following the sun's course caused a twisting from east to west. A tendency to turn in that direction would become finally inherent. This turning might be explained also as a device to prevent the repeatedly dividing branches from interfering; but it appears to be not defined by that use, since the twisting is least marked where the branching is most frequent, as in the lower older part of the zoarium, and moreover the important fact remains that they twist from left to right."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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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DEPOSITION OF THE APPALACHIAN POTTSVILLE*

BY DAVID WHITE

(*Read before the Society January 1, 1904*)

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INTRODUCTION

The purpose of this paper is to present certain general facts respecting the conditions of Appalachian sedimentation which have come to light chiefly through the study of the Pottsville floras. A portion of the results of this study, concerning in particular the nature of the basal Pottsville unconformity and the measures of relative sedimentation, has already been presented in the writer's papers on the fossil plants. The more advanced stage of the paleobotanical work now permits the revision of certain of the conclusions earlier published while further extending their scope in the realm of the physical geography of the

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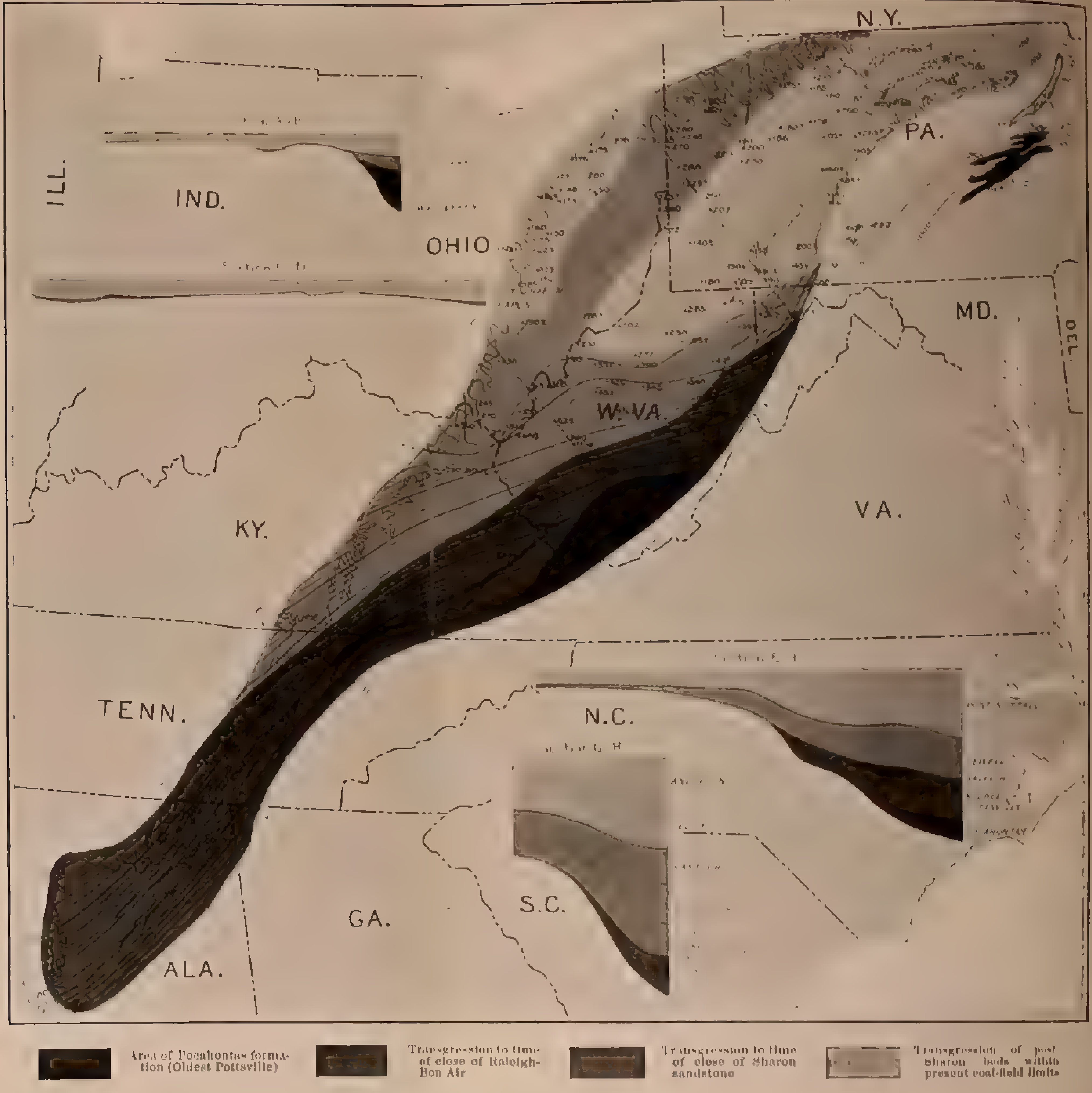

■ Area of Pocahontas formation (Oldest Pottsville)

■ Transgression to time of close of Raleigh-Bon Air

■ Transgression to time of close of Sharon sandstone

□ Transgression of post Sharon beds within present coal-field limits

POTTSVILLE DEPOSITION IN THE APPALACHIAN TROUGH

Contoured to indicate approximately the original thickness of Pottsville sediments, and tinted to show the northwestward transgression of the water level during Pottsville time within the present limits of the coal fields

period. The present paper is, however, to be regarded as preliminary, or as a mere report of progress, and therefore subject to further revision on the completion of the paleobotanical studies.

The Mississippian-Pennsylvanian Unconformity

The existence of an unconformity at the base of the Pottsville series in the Appalachian trough was, I believe, first proposed and insisted on by Dr I. C. White,[*] who remarked the absence of the Sharon conglomerate at points in the northern portion of the Ohio coal field and at several localities near the state line in western Pennsylvania, although in general the thin northern bituminous sections are treated by him as equivalent in time to the entire thickness of the Pottsville sediments in the Southern Anthracite field or the eastern Kentucky coal field.[†] The exact equivalence of the thick and thin Pottsville sections in Pennsylvania is distinctly set forth in the later reports of the state geologists, while the evidence of unconformity is described as obscure and unimportant.[‡]

The study of the fossil plants has shown that the Sharon conglomerate, which constitutes the basal member of the Upper Carboniferous over the greater portion of western Pennsylvania and in Ohio, and which has been regarded as the basal member of the Pottsville in general, belongs in the upper part of the typical Pottsville, and that several thousands of feet of Pottsville sediments in the Southern Appalachian region and a great thickness of beds in the Southern Anthracite basin were laid down before an encroaching sea began the assortment of Sharon material in western Pennsylvania or Ohio.[§]

Figure of the Basin and Thickness of Pottsville Sediments

The nature and extent of the unconformity and the relative thickness of the sedimentation are at once graphically indicated in the accompanying map and stratigraphic profiles. On the map (plate 11) the original thickness of the Pottsville sediments in different portions of the Appalachian Upper Carboniferous coal fields is indicated by 100-foot contours. Assuming that the topmost bed of the series is horizontal, the contouring, verging downward, shows in somewhat generalized form not only the thickness of the beds at various points, but the shape of the floor of the basin at the close of the Pottsville throughout the area of the surviving coal basins.

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[*] Bull. U. S. Geol. Survey, no. 65, 1886, pp. 22, 68, 69.
Rept. Geol. Survey of West Virginia, vol. ii, 1903, p. 610.

[†] Bull. U. S. Geol. Survey, no. 65, p. 202.

[‡] Summary Final Rept., iii, pt. 1, pp. 1807, 1809, 1857, 1858, 1864.

[§] Bull. Geol. Soc. Am., vol. 6, 1895, p. 319.
Twentieth Ann. Rept. U. S. Geol. Survey, 1900, pt. 2, pp. 819, 820–823, 917.

The measurements given on the map for the Pottsville in Pennsylvania and Ohio are largely taken from the respective state survey reports. For West Virginia I have drawn extensively from the wealth of carefully measured sections published by Dr I. C. White in his very important state report lately issued and from the valuable data presented by Mr M. R. Campbell in his folios issued by the U. S. Geological Survey. Special acknowledgment is due Dr J. J. Stevenson for his courtesy in permitting the use of a number of his sections, or interpretations of others' sections, in Kentucky and West Virginia.

In some instances the measurements here given differ from those commonly current. In cases of transitional beds from the Mauch Chunk to the Pottsville the boundary line has been drawn* at the topmost bed of red shale. This cuts off over 400 feet of transitional beds at the type locality, Pottsville, Pennsylvania, which would be included were the boundary placed at the lowest conglomerates in this vicinity, as advocated by Doctor Stevenson. In the Northern Anthracite field the sections have been made to include the lowest red ash beds where the fossil plants of the latter have been found to be of Pottsville age. The upper limit of the Pottsville in several of these sections is not yet definitely fixed, but it is certain that the fossils of the Dunmore coals numbers 2 and 3, in the northern end of the Northern Anthracite field, belong below the top of the Pottsville, the plants from the Clifford bed in the vicinity of Forest City being unquestionably in the Mercer group.†

As elsewhere noted,‡ the Bloss or "B" coals of Tioga, Bradford, and Lycoming counties are referable to the Mercer group and are included in these sections. Departure from the correlations by the Pennsylvania geologists is also made along the Allegheny front in Blair and Clearfield counties, where the fire clays generally placed in the Clarion group are found to lie at the Mount Savage horizon, and so fall within the Mercer group.§

Of a more serious nature is the reduction of the sections in the Allegheny valley and on Red Bank creek in Armstrong and Clarion counties, where the shales above the bed supposed to represent the Sharon sandstone are found to contain plants of types requiring the reference of the terranes to the lower portion of the Mississippian.* It is difficult to conclude how far this condition obtains, but it is probable that the Sharon conglomerate is wanting from a large part of the bituminous area of Pennsylvania.† To a certain extent the sections to the south and west of the Allegheny valley have been interpreted in accordance with the Red Bank sections, but in the more remote instances the measurements here given are subject to revision.

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* Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 831.

† The limits of these, as well as of the sections nearer Shickshinny and Ashley, will be discussed in connection with the full treatment of the fossil floras. The thickness of the Pottsville beds at Campbells Ledge near Pittston is not far from the average for the basin, the measurements by Dr I. C. White quoted in my former papers being confined to the lower members only of the series as deposited at this point.

‡ Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, p. 136.

§ Loc. cit., p. 136. See also Science, vol. xvii, 1903, p. 942.

In West Virginia and Kentucky the upper boundary of the Pottsville is drawn so as to include the Coalburg coal, whose flora at all points furnishing plants is found to fall within the Upper Pottsville. Farther northeast, in northern West Virginia, the line is provisionally drawn at the Roaring Creek sandstone. The Pottsville-Allegheny boundary is not yet closely drawn in the counties of southwest Virginia and northern Tennessee; but the flora in the lower part of the Wise formation ‡ is so old as to render it probable that the entire formation is Pottsville, to which a part of the Harlan is perhaps to be added.§

In the Middlesboro region the highest beds of the Cumberland Valley syncline do not appear to reach the Allegheny, while in the Briceville quadrangle the highest plant beds, less than 250 feet below the topmost point of the Anderson formation, show a mingling of types which in a less expanded series would indicate proximity to the base of the Allegheny, but which in this region may be hundreds of feet from the boundary. South of the Briceville quadrangle the remaining terranes of the Coal Measures do not reach to the top of the Pottsville, though a thickness of over 5,500 feet of beds is reported in the Coosa and Cahaba basins.

The floras of the Alabama coal fields are but partially studied,‖ but it will suffice in this connection to state that the plants of the highest beds, the Montevallo group in the Cahaba field and the Brookwood in the Warrior field, indicate a stage of the Pottsville that is probably below the Sharon conglomerate and certainly older than the coals of the Kanawha. In contouring those portions of the coal field in southern Tennessee and in Alabama, no allowance is made for the higher Pottsville beds which are absent, and the maximum thickness indicated on the map is that reported for the beds remaining in the Alabama basins. It is probable that 1,500 feet or more of additional sediments would be required to carry the section in this region up to the base of the Allegheny. A thickness of 7,000 feet would be hardly greater than that of some of the Millstone Grit sections of Great Britain and considerably less than the Waldenburg group of the Lower Silesian region.

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*See Science, vol. xvii, 1903, p. 942. The inclusion of a portion of the Pottsville of Lesley and I. C. White in the Lower Carboniferous was foreshadowed locally by W. G. Platt (Rept. of Progress, Second Geol. Survey of Pennsylvania, H^5, p. 144; see also p. xv), who referred the sandstone below the silicious limestone on Mahoning creek to the Pocono.

†The writer ventures to suggest, tentatively, that the Lower Connoquenessing, which appears to rest unconformably on the Lower Carboniferous in this region, has in its eastward extension probably been mistaken for the Sharon, and that the coal generally regarded as Sharon along the Allegheny front and in the northeastern counties represents the Quakertown.

‡For descriptions of the Wise and Harlan formations, see Geologic Atlas of the United States: Bristol and Estillville folios, by M. R. Campbell.

§Paleontological material is lacking for the determination of this point.

‖See Science, n. s., vol. iii, 1896, p. 535.

Development of the Basin

GENERAL FEATURES

By reference to the map it will be noticed that the curve of the bottom of the Pottsville basin steepens rapidly toward the eastward and flattens or becomes irregular in passing toward the northwest. The latter is the great region of encroachment or overlap.

One of the facts first to be disclosed by the study of the Pottsville floras is that the thick sections along the eastern border of the Appalachian coal region contain floras distinctly older than those present in the lowest beds of the thin northwestern sections, and that the characteristic floras of the thin sections occur in their natural order in the upper part only of the thick sections.* For example, the flora of the Sharon coal, whose horizon is near the level of the base of the Pottsville in the bituminous regions of Pennsylvania and Ohio, is in the upper part of the deep sections of the Pottsville in the Southern Anthracite field or in southern West Virginia,† while in northern Tennessee it is above the Wartburg sandstone. In other words, the lower Pottsville beds were never deposited in the bituminous regions of Pennsylvania, Ohio, or in northwestern West Virginia.

The nature and extent of the overlap within the surviving Coal Measures areas are best expressed in the accompanying cross-sections of the coal fields on the lines A B, C D, E F, and G H, the exaggerated vertical scale being nearly 2,250 feet to the inch. The correlation of the main divisions of the Pottsville from region to region are chiefly based on the paleobotany of the sections.

POCAHONTAS DEPOSITION

The oldest Pennsylvanian formation yet recognized is the Pocahontas formation of the Great Flat Top region. It is the lowermost Pottsville. In the Pocahontas quadrangle ‡ it is reported to have a thickness of

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* Bull. Geol. Soc. Am., vol. 6, 1895, pp. 319, 320.
Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 819–823.

† Bull. Geol. Soc. Am., vol. 6, 1895, p. 319.

‡ Geol. Atlas of the United States, folio no. 15.

488 feet. The flora of the Pocahontas beds appears to be present near the base of the deepest sections of the Southern Anthracite field*. It has not yet been recognized southwest of the Tazewell, Virginia, quadrangle, perhaps from lack of fossils from its level in this area, and though it probably extends farther along the eastern border of the coal field, the occurrence of large amounts of conglomerate material at the Lower Carboniferous contact and the approach of the Horsepen (Middle Pottsville) floras to the base of the section render it probable that the Pocahontas formation, if present as far south as Cumberland gap, is very thin in the Tennessee region.† Paleontological data are lacking to show whether the Pocahontas horizon is present in the Alabama region, though it would seem that the formation should be represented in so very thick sections. The Pocahontas formation is confined to the eastern boundary of the coal region, where it lies at the base of the very thick sections. Its area is provisionally indicated by the darkest shade on the map.

HORSEPEN-RALEIGH-BON AIR OVERLAP

The next division represented on the map includes the Horsepen group and extends up to the top of the Raleigh sandstone of the New River region. On paleobotanical grounds the Raleigh has been correlated with the Main Sewanee (Bon Air) conglomerate of the Southern Appalachian field and the great sandstone group under Lykens coal number 3 in the Southern Anthracite field.‡ The rocks of this division and the underlying Pocahontas reach a thickness of over 1,200 feet at the eastern border of the New River region. From a preliminary examination of the fossil plants it seems probable that the horizon of the Raleigh is some distance below the top of the Lee of Campbell and Keith along the Allegheny front, near the Virginia-Tennessee line, and such a relation is certain if the Rockwood coal lies in the Sewanee-Sewell zone, as appears to be the case. In the accompanying map (plate 11) the area of Raleigh deposition beyond the supposed confines of the Pocahontas is represented by the shade next lighter than that of the Pocahontas.

SEWELL-SHARON DEPOSITION

In an earlier publication § Raleigh and Bon Air were incidentally correlated with the Sharon conglomerate of the northern bituminous region. Subsequent study of the Sharon coal flora has shown this to be clearly erroneous. The horizon of this flora is much higher than Raleigh and probably as high as the Nuttall sandstone, though it may fall a little lower. Although further study of the plants of the various series may necessitate subsequent revision of my conclusions, the paleobotanical evidence available at present appears to point toward the Nuttall horizon, thus agreeing with the correlation reached by Doctor Stevenson* quite independently and wholly on stratigraphical grounds. The study of the fossil plants from the series of southwestern Virginia and eastern Kentucky is not yet completed,† but it is plain that the horizon of the Sharon coal is fully as high as the top of the Wartburg sandstone of Keith in the Briceville and Wartburg quadrangles of north Tennessee, or the Glade sandstone of Campbell in the Bristol and Estillville quadrangles of southwestern Virginia and Kentucky. The Corbin sandstone on the western border of the Kentucky region would seem, so far as the plants have been studied, to fall near the Glade and Wartburg, and I am provisionally disposed to agree with Doctor Stevenson ‡ in placing Corbin in the Sharon horizon. It certainly is not younger than Sharon. If differing in age, it is older.§

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*Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 817.

†Loc. cit., pp. 817, 818.

‡Bull. Geol. Soc. Am., vol. 6, 1895, pp. 316, 317, 318.
Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 816, 818, 916.

§Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 817.
In a still earlier paper (Bull. Geol. Soc. Am., vol. 6, p. 319, 1895) the Sharon is more nearly correctly compared with the Nuttall.

In the Southern Anthracite field the place of the Sharon conglomerate is about 400 feet below the Buck Mountain coal. It is doubtful if the Sharon was deposited in the Northern Anthracite field or in the northeastern bituminous basins.

SHARON OVERLAP

That portion of the area of Sharon conglomerate which lies beyond the limits of the Raleigh deposition in the Appalachian coal fields is shown on the map by the shade next lighter than that of the Raleigh. Much uncertainty as to the position or even the presence of the Sharon conglomerate in the regions of the Monongahela and Dunkard formations arises from the difficulty of interpreting the drill records in this area in West Virginia, Pennsylvania, and Ohio. The occurrence of the conglomerate is irregular in northern Ohio, and the Connoquenessing sandstone is reported ‖ by Dr I. C. White as resting on the Mississippian in Lawrence county, in western Pennsylvania. It is believed, however, that the mapping is in the main approximately correct. It will be noted that the Sharon area or overlap extends to the northwest far beyond the border of the Raleigh, the Sharon and the supra-Sharon (next to be described) constituting the entire bituminous area of Pennsylvania and Ohio. Over most of this area the Sharon, when present, constitutes the lowest Pottsville terrane.

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*See this volume, p. 206.

†Twentieth Ann. Rept. U. S. Geol. Survey, 1900, pt. 2, p. 819. See age of Breathitt formation.

‡See this volume, p. 206.

§On some accounts it appears possible that the Corbin sandstone may correspond to one of the lentils of the Sewell formation on New river.

‖Second Geol. Survey of Pennsylvania, Rept. of Progress QQ, pp. 68, 69.

POST-SHARON TRANSGRESSION

The remaining area of the coal fields, in which the Sharon is wholly or largely absent,* is represented on the map by the very light tint. This area includes a portion of the northern and the extreme northwestern counties of the northern bituminous regions as well as, probably, the Northern Anthracite field. It is probable that the surface of the greater portion of this region was at or above water level during Sharon Conglomerate time.† It is the surviving area of the final northwest encroachment of the Pottsville sea.

SUBSIDENCE AND EXTENSION OF THE BASIN UNDER LOADING

CHARACTER AND ORIGIN OF THE BASIN

The study of the combined paleobotany and stratigraphy of the existing Pottsville areas in the Appalachian trough shows clearly the existence of a relatively narrow axial trough or series of basins at or beyond the present eastern border of the coal region. In this trough the lowest Pottsville was laid down, and from this axis the northwestward encroachment progressed until the Sharon coal or higher beds were deposited in direct contact with the eroded Mississippian to the north, or on the flanks of the Cincinnati axis to the northwestward.

There is little room for doubt that during the period of Sharon and Kanawha sedimentation, if not earlier, the eastern Pottsville sea extended across Tennessee and southern Kentucky into the Mississippi embayment, which had already probably been reached westward from central Alabama by the close (Bon Air) of the Middle Pottsville.‡ It is certain that the beds of the Sewell formation, lying above the Bon Air-Raleigh sandstone, swept far beyond the present western boundary of the coal field in southern Tennessee, while the Pottsville beds above the Sewell must have been of great thickness in addition.

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* As already stated, this, the lower member of the Pottsville in western Pennsylvania and northern Ohio, is absent in the Allegheny and Red Bank valleys in the region of Armstrong county and it is believed by the writer to be probably absent eastward to the Allegheny front and southwestward beneath a portion of the Pittsburg coal area in northern West Virginia.

† Near the northwest boundary of the coal field in Ohio the Sharon conglomerate is local only and patchy in its occurrence.

‡ As has already been stated, the thicknesses of the Pottsville given on the map are in numerous cases subject to revision. They are, however, accurate for the most part, and the general conditions of sedimentation set forth in the map and cross-sections are well founded.

In drawing the contours in Tennessee trouble is experienced on account of the absence of the supra-Sharon or "Beaver River" series except in the northeastern district of this portion of the coal field. The rate of thinning toward the west is therefore based in part on the observed rate of diminution in the preserved areas and on the behavior of the beds to the north. On account of the absence of information as to the approximate thickness of eroded uppermost Pottsville in Alabama, the region south of the Briceville quadrangle is contoured as though these high formations faded out southward, thus allowing the thickness to fall back to that of the beds still remaining in the Cahaba and Coosa basins.

In the region of the most southerly of the cross sections here presented, the Briceville shale, which corresponds to a portion only of the Sewell, is reported* to thin from 500 to 600 feet at its eastern border to about 200 feet at its last full exposure, less than half way across the coal field, here almost at its narrowest. In this connection it is proper to suggest that a westward gradation of the Briceville into sandstone recognized as Wartburg, or possibly its diminution alone may account for the approach or even the contact of the Wartburg and Lee to the northwest, and the inclusion of the Corbin (Wartburg) in the Lee along the northwestern border of the field near the southern Kentucky line. Further evidence is needed for the satisfactory determination of this point.

POSITION OF EARLY POTTSVILLE AXIS

The existence of an early axial Pottsville basin near the eastern border of the present Appalachian coal region has been clearly shown; but concerning the more exact geography and hydrography of this axial basin much remains to be learned. It seems probable that we approach most nearly to this narrow basin at the eastern border of the Great Flat Top coal field in Virginia and in the Southern Anthracite field in Pennsylvania. The evidence in support of this view consists in (1) the presence at these points of the oldest recognized Pottsville floras, and (2) the existence of transition series. Reference has already been made to the thick transitional beds at the base of the Southern Anthracite field.† Proximity to the eastern land in this vicinity is indicated not only by the gradual passage from red shales and greenish sandstones to gray coal-bearing conglomerates, but by the large size of some of the boulders in the conglomerates. In the Pocahontas region the sedimentation was continuous though relatively rapid from the red and olive shales of the Mauch Chunk through the Lower and Middle Pottsville without the introduction of conglomeratic sediments. In this region there is no unconformity between the Mississippian and the Pennsylvanian.‡ Farther to the southwest, toward the Tennessee line, although the total Pottsville sediments are thicker, the contact of the Coal Measures with the Mississippian is sharper, with the immediate introduction of massive conglomerates, while the interval below the Raleigh is much lessened, if I am right in regarding the Rockwood coal as overlying the Bon Air conglomerate. I am therefore disposed to believe that between the region of the Tazewell, Virginia, quadrangle and central Alabama the present eastern margin of the coal field falls slightly west of the axis of the trough.

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*See Arthur Keith: Briceville folio, no. 33.

†See Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 831.

‡In his earliest papers on the subject the writer suggested that the lower portions of some of the thick eastern sections of the Pottsville might have been laid down near or in deltas contemporaneously with the highest red or green Mauch Chunk beds of some other region. This still appears possible; but that such a condition continued for any considerable length of time or beyond the earliest Pottsville is very improbable.

If we have to do with a narrow basin rather than a series of small basins along the axis, it is probable that the early Pottsville trough swept southwestward with a gentle curve from the Southern Anthracite field toward the border of the Great Flat Top region south of New river. This is indicated by the very rapid steepening of the floor of the basin along the margin of the coal field in eastern West Virginia.*

Southward from the Great Flat Top region the axis is assumed to have lain east of the present coal field, though it is possibly reached in the Coosa and Cahaba fields, where, notwithstanding the rapid westward thinning of the series, it would seem that a great thickness of the Lower Pottsville must be present, since even in the heart of the Warrior basin a depth perhaps exceeding 1,400 feet of Lower Pottsville appears to be sweeping westward with relatively slow diminution toward the Mississippi line and the great embayment.

EASTERN MARGIN OF THE BASIN

Respecting the eastern margin of the Pottsville basin, there is room for great difference of opinion. It would seem, however, that the deep basin at the present margin of the southern Anthracite field must have been near the scene of orogenic movement. In the Southern Appalachian region the coarsely conglomeratic material is less both as to size and relative amount, though the extent of the formation is far greater. On account of the absence of residual masses of Pottsville in the Clinch Mountain syncline of southwest Virginia, Mr M. R. Campbell is disposed to believe that the Pottsville did not extend as far east as Clinch mountain in the Estillville quadrangle. On the other hand, the rapid loss of the beds up to and including the Bon Air-Raleigh within a relatively short distance from the eastern margin of the field † shows that the axis could not have lain far westward along a zone extending nearly to the latitude of the center of the Warrior coal field. In the opinion of the writer, the basin in early Pottsville time extended a considerable distance to the eastward of the present coal-field limits in the Southern

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*The reported thickness of the Pottsville in the Broad Top field, if accurate, would seem to locate that area on the verge of the overlap of the eastern Sharon as illustrated on the map.

† See M. R. Campbell: Huntington, Standing Stone, Richmond, and London folios.

Appalachian region. It is probable that there was some encroachment of the sea to the eastward also, particularly as the result of the extraordinary subsidence under loading along the early axis. This, however, may have been checked by the continuation of the orogenic movement.

The question as to whether the narrow axis of the early Pottsville was a continuous basin or was composed of several basins lacks evidence of a conclusive nature. The presence of a brachiopod fauna in the Middle Pottsville (Horsepen) as far north as Sewell, on New river, seems to justify the belief in a free access to marine animals from the broad end of the trough to the southward at this time. In Pennsylvania the paleontological evidence as to communication of the early basin with the open sea rests on the occurrence of *Naiadites* and *Spirorbis* in the Lower Lykens group of the Anthracite region. At the time of Mercer Group deposition the Pottsville sea was broad and open, so that marine faunas are found in various regions of the trough.

AMOUNT OF POTTSVILLE SEDIMENTATION

An imperfect conception of the dimensions of the basin at the close (Raleigh-Bon Air) of Middle Pottsville time may be had from the contouring and coloring in the accompanying map; but in estimating the contents of the entire Pottsville basin one must bear in mind (1) that the territory of the post-Bon Air encroachment lay entirely to the west of the surviving Coal Measures area south of the Standing Stone, Tennessee, quadrangle, and is but partially preserved for observation north of the latter until we reach the Ohio river; (2) that no allowance is made for the supra-Sharon (Kanawha) beds, presumably 1,500 feet or more in thickness, in Alabama; and (3) that the basin is truncated at its present eastern border, the deepest (though perhaps narrow) portion having been removed. With these facts in view one may estimate the extent of the orogenic movement to the eastward and the amount of erosion of the old Blue Ridge region required to furnish the Pottsville sediments. It is particularly remarkable that the region of greatest movement and greatest sedimentation is in the extreme Southern Appalachian region, where, if the measurements of the Coosa and Cohaba basins are correct, sands, coals, and clays over a mile in thickness were laid down before Sharon time. Even within the present confines of the coal fields, the amount of the Pottsville sediments in the Southern Appalachian region was several times that of all the existing rocks lying above the 1,000-foot contour in the region to the eastward.

From the facts set forth above, it will be seen that nearly all of the present Appalachian Coal Measures area bears the marks, either paleontological or stratigraphical, of the continued transgression of the sea.

The Raleigh-Bon Air and Sharon conglomerates are at once evidence of orogenic movement, on the one hand, and sea encroachment, on the other. Stratigraphically each is transgressive, and I am disposed to believe that the materials forming these beds, which are sometimes thicker near their western outcrops, were in no small part obtained by reworking of the coastal plain deposits. The disposition, form, and structure of the little basins of Sharon coal along the northwest border of the field are in strong evidence of such conditions.

ARCHES OR BARRIERS WITHIN THE BASIN

The study of the thickness and distribution of the sediments in the region of northwestern encroachment suggests the existence of one or more barriers or islands until very late Pottsville time. From (*a*) the rapid thinning of the sections toward the northwest in the Northern Anthracite region, (*b*) the thinness of the sediments in the small northeastern bituminous basins of Pennsylvania, (*c*) the thinning of the Pottsville on approaching the Allegheny front* in Clearfield and Cambria counties, (*d*) the reported thinning of the Broad Top Pottsville in passing northwestward, and (*e*) the apparent absence of the Sharon sandstone from this region, it would seem that a very low barrier extended from the northeast through Bradford, Tioga, and Lycoming counties and along the eastern margin of the Allegheny front, possibly passing to the west of the Frostburg basin and dying out. The evidence contained in the sections published by I. C. White, Stevenson, W. G. Platt, and Chance in their reports for the western counties of Pennsylvania shows the presence of an area of Sharon sandstone extending from Ohio eastward across the western tier of counties of the former state, while east of these, in the Kittanning-Redbank region of the Allegheny valley, as is shown by paleobotanical and stratigraphic studies, a barrier of Mississippian continued in erosion until overswept by the waters of the greatly broadened basin in Connoquenessing time. Westward of this barrier, which probably passed near Pittsburg, an arm of the sea extended during Sharon time northeastward through Ohio and into the western counties of Pennsylvania. If the Pottsville measurements given in the state reports from Indiana, western Clearfield, and northwestern Cambria counties are correct, a shallow syncline of the Mauch Chunk floor may have lain to the east of the Allegheny valley; but on this matter additional evidence is needed. The decreased measurements reported on the south side of the Northern Anthracite field and along the northwestern border of the Eastern Middle Anthracite field, if correct, distinctly indicate the presence of a low ridge in Sharon time between these two anthracite fields. The formation of such minor undulations to the westward of the deep narrow trough of the basal Pottsville on the occasion of the deformation of the old Mauch Chunk floor at the beginning of Pottsville time would be normal and entirely comparable to the orogenic movements which formed the deep basins to the eastward at the close of Paleozoic time.

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* The thicker measurements of the interior of the coal field are based on the state reports.

PHYSICAL EVIDENCE OF THE POTTSVILLE TRANSGRESSION

Although it is the writer's purpose to confine the scope of this paper to the principal propositions that have originated in and have been gradually worked out mainly through the study of the fossil floras, brief reference should be made to some of the stratigraphic evidence in support of these propositions. The overlap and unconformity of the Bon Air conglomerate beyond the limits of the earlier Pottsville terranes in the outlying patches of Coal Measures in northern Alabama and along the western margin of the coal field in Tennessee has long been recognized. Farther north, in southern Kentucky, Mr M. R. Campbell * notes the occurrence, to the northwest of the Bon Air area, of a river channel which was filled by Rock Castle sediments. This river was obliterated by the post-Bon Air transgression and before Corbin time, which at latest is early as Sharon.† Reference has already been made to the Allegheny valley, where Pottsville beds regarded as Lower Connoquenessing ‡ rest on shales of Pocono (Lower Mississippian) age.

The physical discordance between the Mississippian and the Pottsville is greatest near the northwest border of the coal field in Ohio and Pennsylvania. Toward the south in Ohio the Sharon rests on the Maxville limestone. Farther north the Sharon is often wanting along the flank of the Cincinnati axis, and the Lower Connoquenessing sandstone rests in places on the Shenango shales or the Logan. In McKean county, Pennsylvania, the Mississippian is eroded, so that Sharon or higher beds rest on beds of Pocono age. The interval between the uplift of the Mauch Chunk mud flats at the beginning of Pottsville time and the supra-Sharon encroachment—that is, the period of erosion of the Mississippian in northwestern Pennsylvania—is measured by the time required for the erosion and redeposition of a great thickness of earthy sediments exceeding a mile in depth in the southern portion of the basin, added to the time required for the accumulation of the vegetable matter in a great thickness of coal beds. The lapse of time is hardly less forcibly demonstrated by the remarkable changes in the plant life.

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*Atlas of the U. S. Geol. Survey, London folio.

†Stratigraphical evidence confirmatory of these transgressions is coming to light in the quadrangles studied by the U. S. Geol. Survey. The data at hand have been excellently summarized by Dr J. J. Stevenson in his paper on the Stratigraphy of the Pottsville, this volume, p. 37.

‡ The Connoquenessing sandstones lie above the Sharon sandstone and shales.

SUMMARY OF APPALACHIAN POTTSVILLE HISTORY

From the data now available it is possible to sketch a portion of the history of the Appalachian coal field during Pottsville time. It may be outlined as follows:

1. At the close of Mauch Chunk time there existed a broad, low country or great coastal plain bordering a vast expanse of shoals, ferruginous mud flats and shallows extending across the greater part of the region of the northern coal fields. The Pocono activity of erosion had subsided. These great stretches of Mauch Chunk flats were marked by ripple marks, sun cracks, reptilian footprints, and raindrops. There appears to be no evidence of deep water in any considerable part of the northern Appalachian basin at this time.

2. These relatively quiescent conditions were followed by orogenic movement, the lifting of the western and by far the greater part of the Mauch Chunk above sealevel, while mountain-building took place to the east. and, concomitantly, the eastern border of the Mauch Chunk shallows was warped to form a relatively narrow trough, presumably flanking the mountain region. It is possible that other, more gentle undulations occurred, to the northwestward, remaining low arches or barriers being more or less distinctly indicated (1) between the Eastern Middle and the Northern Anthracite fields, (2) east of the Allegheny front in Pennsylvania, and (3) along the Allegheny valley in western Pennsylvania. Erosion was accelerated and rapid sedimentation, with some redeposition of the Mauch Chunk coastal plain sediments, took place. This was the earliest stage of the Pottsville.

3. There was subsidence under loading with occasional intervals of stability in which coals were formed. Westward transgression by the sea resulted from the subsidence of the basin, with some warping and angularity of stratification. In early Pottsville time marine invertebrate faunas reached as far north as central West Virginia,* though it is probable that the basin was still of no great width.

4. Sedimentation and intermittent subsidence continued, with broader encroachments during the latter part of the Middle Pottsville and Raleigh-Bon Air time when the transgression passed the present western limits of the coal field in Alabama and southern Tennessee and made great pro-

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* The fauna of the lower Pottsville in the Southern Anthracite field is of a kind less conclusive as to marine conditions.

gress in Kentucky and southern West Virginia. It is probable that the orogenic movement to the eastward was more or less progressive.

5. There appears to have been relative steadiness during the greater part of Sewell time (Upper Pottsville, in part), though sedimentation was very rapid in the Southern Appalachian region; but subsidence evidently continued, and the period including the Sharon conglomerate marks another great encroachment when the sea overspread the present bituminous region of Ohio and Pennsylvania, transgressing the eroded and somewhat uneven Mississippian floor until the Connoquenessing sandstone came into contact with the Pocono or basal Mississippian here and there along the northern shores or the flank of the Cincinnati arch to the northwest. The conclusion of the Homewood stage—that is, the close of the Pottsville—probably saw the shoreline removed some distance beyond the present limits of the coal fields in the northern region,* though there is room for doubt as to whether it crossed the Cincinnati axis in Ohio and thus made connection with the Michigan coal field. It is highly probable that by this time the Pottsville sea swept across the Cincinnati arch in southern Kentucky and Tennessee, so as to connect with the interior region, which may already have been reached farther south, westward from central Alabama, at a time perhaps as early as the Bon Air stage.

Continuity of sedimentation from the Mauch Chunk to the Pottsville without abruptness of lithological change is evident only at the base of the Pocahontas formation on the eastern border of the Great Flat Top coal field in southwestern Virginia.† Both northward and southward from this district the lower and middle Pottsville, when present, are generally characterized by massive conglomerates, though often the contact is not sharp between the latter and the green or red shales of the Mississippian. The conglomeratic phase of the older Pottsville is conspicuous near the Tennessee line and in the Southern Anthracite coal field.

The Raleigh-Bon Air stage marks an interval of most widely distributed sandstones or conglomerates throughout the greater part of the limits of the at that time much restricted basin. It is doubtful, however, whether the northern portion of the basin, including the present Southern Anthracite field, was as yet accessible to marine molluscan life. The

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*As has been elsewhere stated, the Mercer group of the northern region, with its refractory fine clays, limestones, coals, and iron ores, undoubtedly represents a duration greatly disproportionate with its thickness. The Mercer group and Connoquenessing sandstones appear to represent by far the greater part of the Kanawha formation in southern West Virginia, and a thickness probably still greater in the eastern Kentucky-Virginia region. See Science, vol. xvii, p. 942.

†The Flat Top district is, as compared with other thick sections of the Pottsville, particularly notable for the almost complete absence of conglomerates in the Pennsylvanian.

Nuttall sandstone represents another broadly extended arenaceous sheet, though it is less distinct to the southward, where the entire Pottsville section is marked by the frequent recurrence of massive sandstones, many of which, in the Alabama coal fields, are conglomeratic. The Mercer group, of relatively insignificant thickness and deposited under quiescent conditions in western Pennsylvania, is represented by more or less conglomeratic beds in the anthracite districts, while in the central and southern Appalachian regions its representatives, at the top of the Kanawha formation of southern West Virginia and in the Wise formation of southwestern Virginia, are greatly expanded and but little distinct lithologically from the strata enveloping them. In Tennessee the Anderson formation, whose lower half at least is Mercer, marks another period of increased proportion of the arenaceous sediments throughout the central and southern Appalachian region. The Anderson appears to be laterally continuous with the Harlan sandstone of eastern Kentucky and the Charleston sandstone of the Kanawha region of West Virginia.

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MOLYBDENITE AT CROWN POINT, WASHINGTON

BY A. R. CROOK

(Presented before the Society December 30, 1903)

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INTRODUCTION

The occurrence of molybdenite (MoS_2) at Crown Point, Chelan county, Washington, is one of the most interesting in the United States for several reasons: First, because practically the entire commercial supply of the mineral in the United States for 1902 was mined at this locality. The amount is given by Dr J. H. Pratt as about twelve tons of ore.* Second, because the locality presents an interesting illustration of the geologic relations of the substance; and third, because so large a quantity of this comparatively rare mineral naturally furnishes excellent specimens representing the mineralogical character of molybdenite.

Commercially molybdenite is important as the chief source of molybdenum. This element has long been used as a pigment for coloring silk, leather, and porcelain. The color which it furnishes is a brilliant, uniform, and permanent blue, and is especially prized for glazed ware.

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* Mineral Resources of the United States, 1902, p. 7.

Molybdenum finds a limited use in chemical laboratories for the detection of phosphoric acid and as a medicine for the cure (?) of dropsy.* The chief demand for the element, however, is one which has arisen recently in the manufacture of steel, a fraction of a per cent producing an effect analogous to that obtained by the employment of wolfram and nickel. The price paid for molybdenite ores varies to a surprising degree, from $150 to $1,500. The variation is caused largely by the presence or absence of chalcopyrite, a small amount of the substance having a very deleterious effect.

LITERATURE

Though the Chelan deposit has been known and worked for a number of years (since 1897 or 1898), the literature in reference to it is meager. In Hintze's comprehensive list of occurrences it is not mentioned. The only references which the writer has found are in the Washington Geological Survey report for 1901 † and the "Mineral Resources of the United States" from 1899 to 1902.

A short visit to the mine in 1902 enabled the writer to collect specimens of the mineral, gangue, and country rock, and to take photographs of the lode.

OCCURRENCE OF MOLYBDENITE AT OTHER LOCALITIES

PETROGRAPHICAL RELATIONSHIPS

At fifty or more localities in different parts of the world where molybdenite is reported, it occurs in a great variety of rocks and associated with many different kinds of minerals. A survey of these occurrences shows that it is found in practically all of the main groups of rocks, as the following list will indicate.* It is found in

1. Conglomerate (Switzerland).
2. Granular limestone (Hessen, Ungarn).
3. Contact of marble with pyroxenite (California).
4. Serpentine (Tirol).
5. Garnetite (Hessen).
6. Amphibolite schist (Finland).
7. Chlorite schist (Kärnten, Sweden, Finland).
8. Talc schist (Finland).
9. Mica schist (Switzerland, Sweden).
10. Gneiss (Baden, Mähren, France, Norway, Connecticut).
11. Basalt (Sardinia).
12. Pyroxenite (Canada).

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* Fuchs et Delauney: Traité des Gites Mineraux et Metalliferes, 1893, ii, p. 175. D. C. Davies: Earthy and other Minerals, and Mining, 1892, p. 324.

† Washington Geol. Survey Annual Report, vol. i, pp. 92-93.

13. Gabbro (Harz).
14. Syenite (Norway).
15. Granite (Schläsien, Böhmen, Bayern, England, Norway, Ceylon, Tasmania, New South Wales, Victoria, and various parts of Canada and the United States).

This last named occurrence—that is, with granite—is by far the most usual and typical.

ACCOMPANYING MINERALS

The mineral association is not less varied than its petrographical relationships. It is associated with the following minerals, arranged in mineralogical order: Silver and gold, sphalerite, pyrrhotite, pyrite, bornite, chalcopyrite, arsenopyrite, fluorite, quartz, magnetite, cassiterite, rutile, calcite, orthoclase, oligoclase, pyroxene, tremolite, hornblende, garnet, scapolite, zircon, tourmaline, muscovite, biotite, apatite, barite, wolframite, scheelite—some thirty minerals in all.

The association with sulfides and oxides is that most characteristic of the occurrence in quantity in veins. The association with carbonates and silicates is that shown by particles disseminated in rock masses.

FORM OF DEPOSITS

The form of the deposit shows some variety, inasmuch as the mineral under consideration is found in rifts, impregnations, in quartz druses, in beds and lenses, in beds of magnetite, in copper and cassiterite veins, in veins of compact tremolite, and in veins of fluorite, barite, and most commonly quartz. Lacroix† says that molybdenite is rarely found in metalliferous veins.

LOCATION OF CROWN POINT MINE

Chelan county is a little north of the center of Washington. Through it from southeast to northwest stretches lake Chelan for about 60 miles in a narrow rock gorge from 2 to 4 miles in width. In many places the banks are so steep that a fisherman could not find standing room. The mountains rise 5,000 feet or more above the lake. In rugged beauty this lake is probably unsurpassed by any of the lakes of North America. Its picturesqueness has been well described by Russell.‡

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* An extended list of localities is given in Hintze's Handbuch der Mineralogie, i. See also:
Lacroix: Min. de l. France, tome 2, p. 461.
Mugge: N. Jahrbuch, 1898, i, p. 109.
Chelsius: N. Jahrbuch, 1902, i, p. 336.
Bell: Transactions Am. Inst. Mining Engineers, xiv, p. 692.
American Journal of Science, 1886, 1889, 1898.

† Mineralogie de la France, 2, p. 461.

‡ I. C. Russell: Lakes and Rivers of North America.

Twelve miles from the head of the lake, on the southwest side, opens up a valley which extends 20 miles westward to near the summit of the Cascades. It discloses folded metamorphic and igneous rocks. Through the valley runs Railroad creek, making a fall of 4,000 to 5,000 feet in 20 miles from its source to the surface of the lake, which is only 1,100 feet above tide level. At the head of the valley rises a granite cliff so precipitous that many would-be visitors to the mine withdraw without attempting the ascent.

That the molybdenite-bearing ledge was ever discovered is surprising, and gives an indication of the minute scrutiny with which prospectors have gone over the country. The first tunnel is 900 feet above the miners' cabin at the foot of the cliff, and the face of the cliff makes an angle of from 60 to 80 degrees from the horizontal. Access to the mine is made possible by a rope fastened to an iron peg in the rocks (plate 12, figure 1).

Form of the Deposit

The molybdenite occurs in a quartz vein, a blanket vein outcropping along the nearly perpendicular face of a granite cliff for several hundred feet. In general, it is nearly horizontal, but at times has an inclination of from 5 to 6 degrees toward the west (plate 12, figure 2). Its average thickness, which is from 2 to 3 feet, and the general horizontal position are well shown in plate 13, figure 1). Two tunnels have been driven into the cliff, one extending 195 feet toward the northeast and the other 80 feet westerly. There are something more than 100 feet of open workings. The molybdenite does not occur near the center of the vein. Thus it differs from the Mono county, California, occurrence.* At Crown Point it is found in small seams several inches in thickness, extending in all directions through the quartz vein from side to side. At no time is the molybdenite found in the accompanying granite, but is always separated from it by a layer of quartz.

Inclosing Rock

The rock in which the molybdenite-bearing quartz vein is found is a greenish gray biotite granite. It is from medium to fine grained, and even in texture. Of the composing minerals, the quartz is firm, compact to granular, with occasional crystal faces, and usually glassy and white when not discolored by iron oxides. The feldspars are opaque and colored greenish by the decaying biotite, which is changing to chlorite. Thin-sections show under the microscope that the quartz is well filled with fluid inclosures and is xenomorphic in relation to the feldspar and biotite. The feldspars are so kaolinized as to be almost

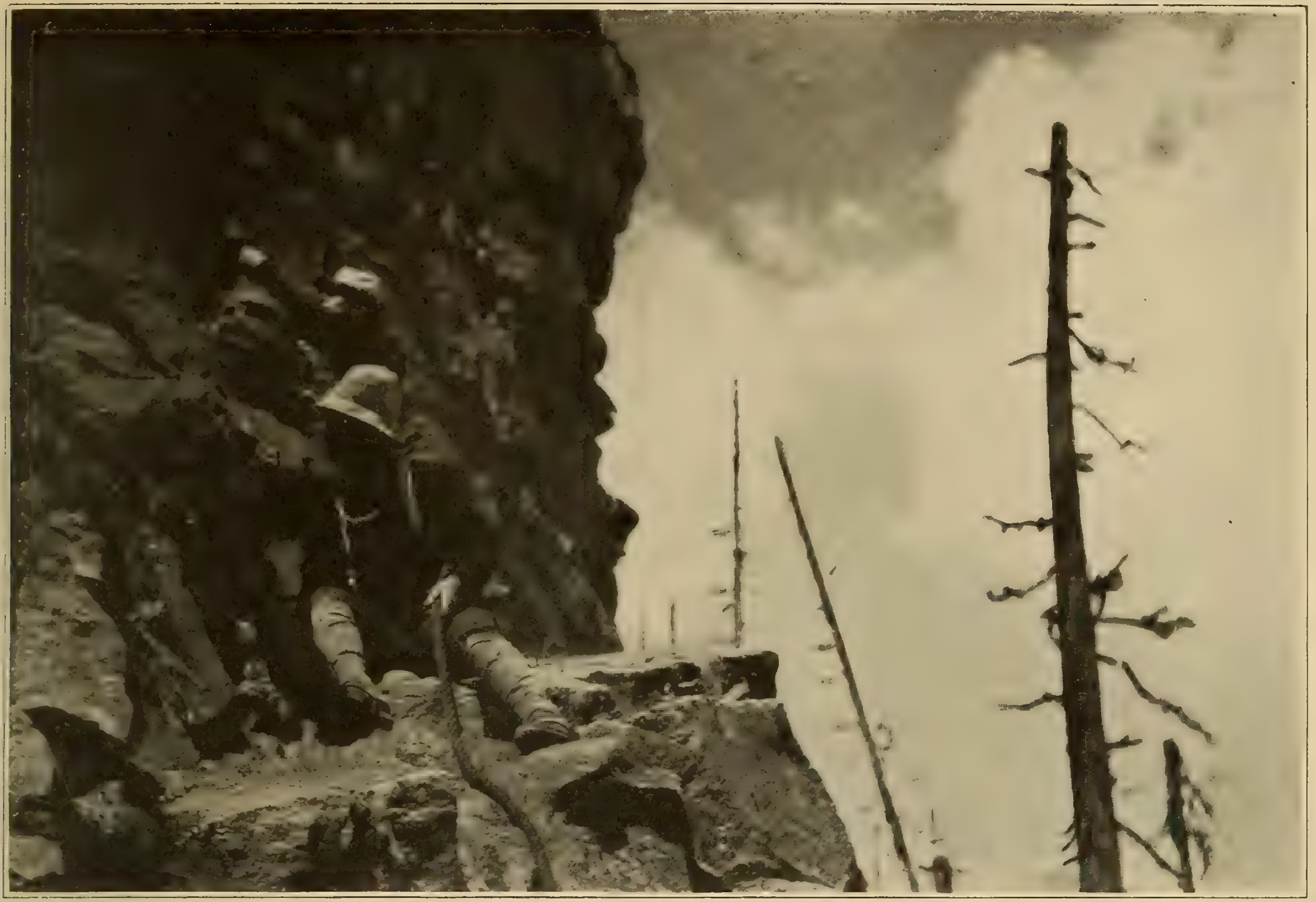

Figure 1.—Granite Wall containing Molybdenite Vein

This vein is 900 feet above miner's cabin

Figure 2.—Dip of Quartz Vein at First Tunnel

MOLYBDENITE-BEARING VEIN IN GRANITE

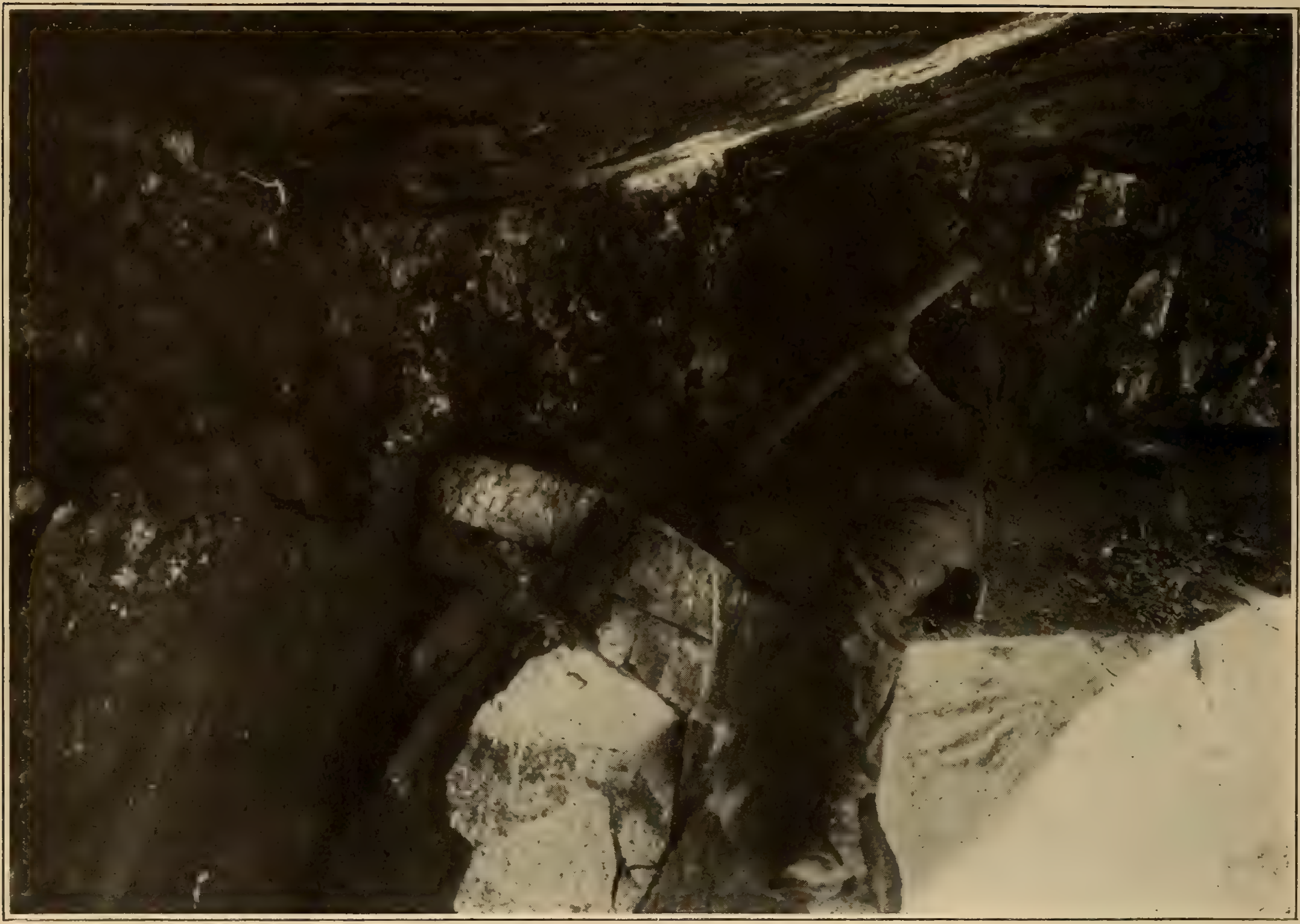

Figure 1.—Horizontal Quartz Ledge at a Point Rich in Molybdenite

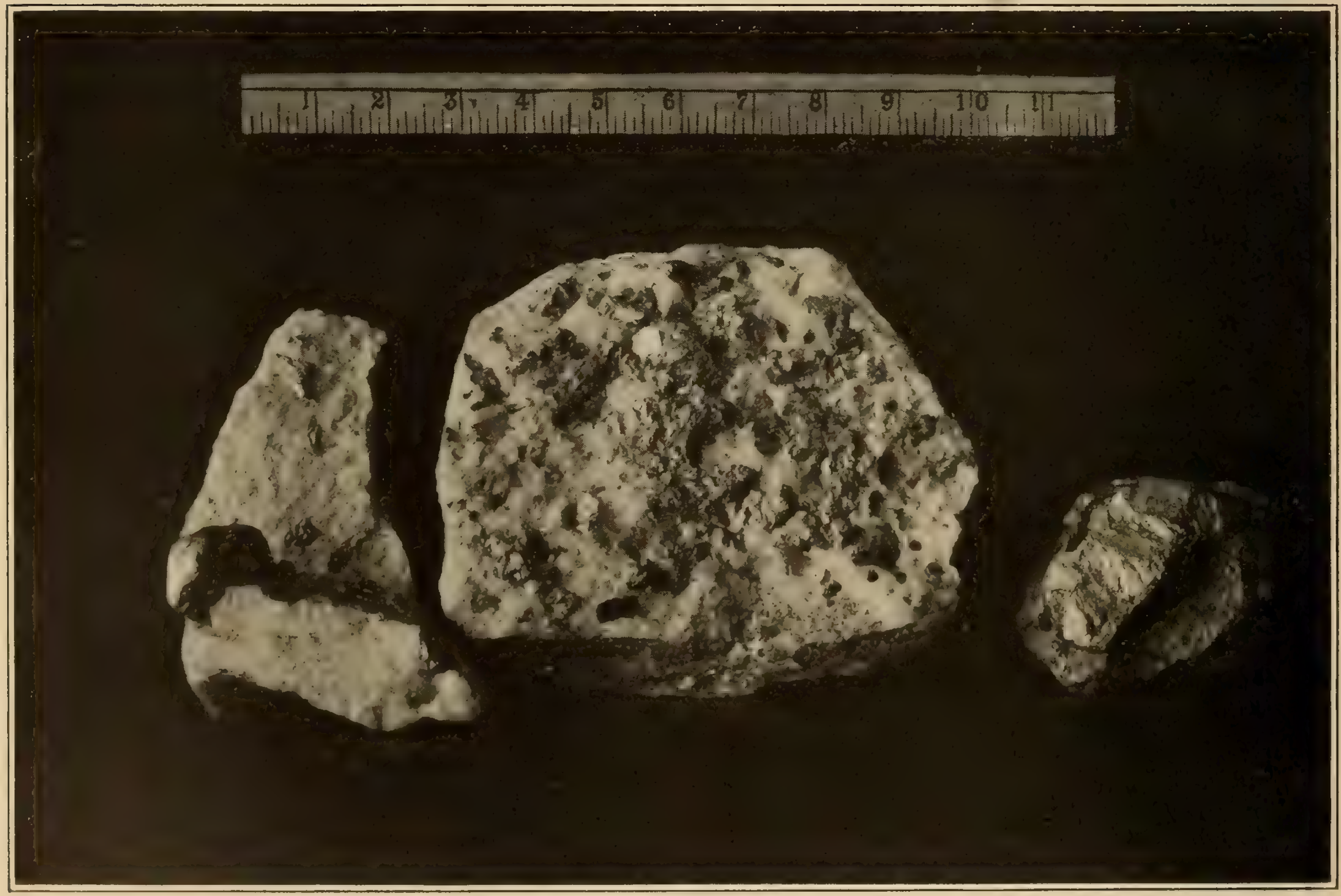

Figure 2.—Molybdenite Crystals in Quartz

MOLYBDENITE IN QUARTZ

devoid of optical properties. The biotite occurs in large bunches and tufts. It discloses various stages of chloritization. The accessory minerals are few and unimportant.

ANALYSES

Two analyses of the granite made by Miss Zaumbrecher and two by Mr J. N. Pearce, of Northwestern University, failed to show molybdenum in the granite. This is somewhat surprising, since this element is notably at home in acid igneous rocks.† This would seem to indicate that the molybdenite in the quartz veins was not derived by lateral secretion.

CHARACTER OF THE MOLYBDENITE

The molybdenite occurs in crystals and flakes of varying size (plate 13, figure 2), from minute specks to irregular masses, sometimes 20 millimeters in diameter. The crystals show the characteristic rifts parallel to the side of a hexagonal prism. The prism faces, however, are rarely developed, but the usual form is that of flat pyramids which are built up as shown in plate 13, figure 2. The majority of these pyramids are very beautifully and strongly striated, the striations being parallel to the union of the prism face with the base. Cleavage surfaces are not smooth and unmarked, but are divided by lines elevated at right angles to edge of intersection of pyramid with base, explained by Mugge ‡ not as "glide planes," but rather as the result of bending with "translation" parallel to base (0001). Bent planes are common, and, in addition, evidence of torsion due to molecular stress.

These crystals furnish no new facts upon the crystallography of molybdenite. Being opaque, it is not possible to use optical methods in their study, and hence one of the best means of determination is wanting. It is generally agreed, however, that the mineral is hexagonal, according to the measurements of Brown.§ Repetition twinning in some of the crystals examined seems to accord with this determination. The crystals show fine luster and are very pure.

PARAGENESIS

The molybdenite crystallizes sometimes before and sometimes after the inclosing quartz. For example, in localities, as in Silesia, it is found

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* Mineral Resources of the United States, 1901, p. 266.

† Hillebrand; Bulletin U. S. Geol. Survey, no. 167, p. 53.

‡ Mugge: N. Jahrbuch d. Min., 1898, i, p. 109.

§ A. P. Brown: Proc. Acad. Nat. Sci., Philadelphia, 1896, p. 210.

capping quartz crystals in quartz geodes. At Salzburg it fills out the cavities between well defined quartz crystals. At Crown Point the molybdenite is always separated from the granite which incloses the quartz vein by a layer of quartz, but the quartz is xenomorphic toward the molybdenite, since the form and striations of molybdenite are always evident in the quartz in which the molybdenite crystal is imbedded.

Associated Minerals

As far as the writer is aware, molybdenite is not associated with gold and silver at Crown Point. None of the specimens examined contained either of these metals. The statement of such occurrence made in "Mineral Resources of the United States," 1901, should probably apply to the Holden mine,* a few miles farther down the valley. Some distance from the outcropping of the vein toward the inner part of the tunnel chalcopyrite appears mixed with the molybdenite. The absence of chalcopyrite near the outcropping may be due to the fact that it has been oxidized. It is well known that even in museums the iron sulfide is preserved with difficulty in the presence of moist air. Upon the addition of water to the mineral, pyrite or marcasite readily change into melanterite, which is easily dissolved. The chalcopyrite, while more stable, in open air readily passes into the sulphate, which can be dissolved, and is washed away without leaving a trace. This is a probable cause of the absence of copper ores near the surface.

Source

The suggestions as to the source of molybdenite are mainly negative. If we assume, which is more than probable, inasmuch as the element is not now present, that the neighboring rock at no time contained molybdenite, the source could not have been from lateral secretion. If the neighboring rock did contain the substance, it would be difficult to conceive of leaching so thorough as to remove the last trace; hence we are led to conclude that the material must have been born by descending or ascending waters, and I see no facts to suggest a choice of the alternatives.

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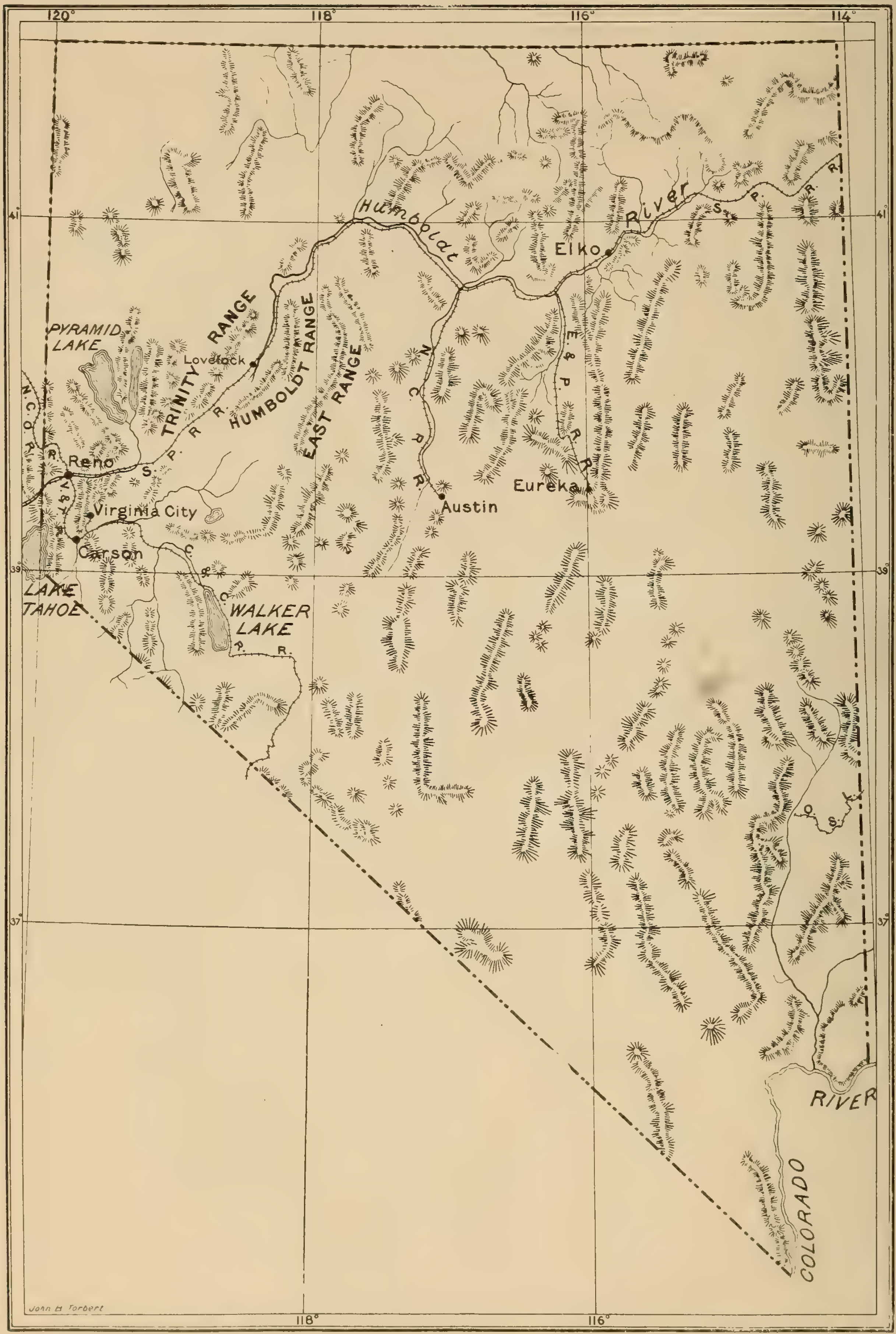
*Mineral Resources of the United States, 1901, p. 266.


120°
118°
116°
114°
41°
39°
37°
Humboldt
River
S. P. R. R.
Elko
PYRAMID LAKE
Lovelock
TRINITY RANGE
HUMBOLDT RANGE
EAST RANGE
N. C. O. R. R.
Reno
V. & T.
Virginia City
Carson
LAKE TAHOE
C. & C. R. R.
WALKER LAKE
N. C. R. R.
Austin
E. & P. R. R.
Eureka
O. S. L.
RIVER
COLORADO
John B. Forbert

INDEX MAP OF NEVADA

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BASIN RANGE STRUCTURE OF THE HUMBOLDT REGION*

BY GEORGE DAVIS LOUDERBACK

(*Presented before the Society January 1, 1904*)

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*Published by permission of the Carnegie Institution of Washington. The main points of the paper, as far as the Humboldt Lake range is concerned, were presented before the Cordilleran section of the Society December, 1902. Another field trip was made in June, 1903, for the purpose of getting a more accurate topographic section and of extending the work to Table mountain. The latter trip and preparation of results was made by the writer as research assistant of the Carnegie Institution. The writer is indebted to Professor G. J. Young for surveying, by transit and stadia method, the profile for the detailed section.

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Introduction

The existence of mountain ranges in western America formed by the tilting or relative uplifting of great blocks of the earth's crust, acting as comparatively rigid masses, with subordinate or no flexing or folding of the strata, was first pointed out by G. K. Gilbert in 1873.* He presented and discussed a number of sections and descriptions of ranges in Utah and eastern Nevada, showing the futility of any folding and denudation hypothesis, and the applicability of the notion of origin by faulting. As the ranges of the Great basin form a rather distinct geographical system, and as the faulted block structure was supposed to be the prevailing type, Gilbert discussed it as the structure of the Basin Range system. Not long afterward, Powell,† in outlining the different types of mountain origin, described the formation of mountains by the tilting of faulted blocks as the "Basin Range type."

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* U. S. Geographical Survey West of the Hundredth Meridian (Wheeler Survey), vol. iii, pp. 21–42.

† U. S. Geol. and Geog. Survey of the Territories; Geology of the Eastern Portion of the Uintah Mountains, p. 16.

This view of the origin of the ranges of the Great basin was accepted more or less completely by the other geologists who later worked in that field. In particular, I. C. Russell, during his investigations into the history of lake Lahontan, made observations on the mountain ranges of western Nevada and adjoining territory, which convinced him of the persistence of this type of mountain structure throughout the Western Basin region. In his monograph on lake Lahontan he publishes a map* showing the position of the fault lines along which the blocks were raised or depressed to form the ranges. He also shows by another map, and by a plate,† the lines along which he has observed evidences of Recent faulting. As these Recent fault lines coincide with the lines of earlier faulting, he regards them as indicating a continuation of the earlier movements along the same lines in Recent time. The forces may be active even now.

The geologists of the Fortieth Parallel Survey had originally believed that the ranges were formed by folding and were "ordinarily the tops of folds whose deep synclinal valleys are filled with Tertiary and Quaternary detritus."‡ But after the publication of the views of Gilbert and of Powell, King accepted the idea of monoclinal blocks formed by faulting as a prominent characteristic of the Basin region, but at the same time he insisted on the importance of the folding of the region by lateral compression. He says:§

> "The geological province of the Great basin, therefore, is one which has suffered two different types of dynamic action: one, in which the chief factor evidently was tangential compression, which resulted in contraction and plication, presumably in post-Jurassic time; the other, of strictly vertical action, presumably within the Tertiary, in which there are few evidences or traces of tangential compression."

Russell and other later workers also recognized these two types of structure in the Great basin—the "enormous and complicated folds, riven in later times by a vast series of vertical displacements."‖

Professor Le Conte presented an interesting general conception of the genetic relations of these ranges. The Great Basin region, most, perhaps all, of which was under the water of the ocean during Paleozoic or Mesozoic time, has been elevated as a whole in such a way that the higher peaks, notwithstanding erosion on a great scale, are from 10,000 to 15,000 feet, and even the broad valleys of its northern part are from four to six thousand feet above the level of the sea. Le Conte conceived that elevated portion of the earth's crust between the Sierra Nevada on the west and the Wasatch on the east, in the course of its slow upheaval to its present exalted position, to be something like a great arch, the incompetent material of which was continually readjusting itself by breaking down into blocks that gradually shifted along planes of normal or gravity faulting. The upturned edges or elevated tops of some blocks form the mountain ranges; the downthrown edges or depressed tops of others, the intervening valleys. The Sierra Nevada forms one end of the great arch, with its mighty scarp facing eastward, the Wasatch being its counterpart on the far eastern limb, with its scarp facing westward.*

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* U. S. Geol. Survey, Monograph xi, plate iii.

† Ibid., plates xliv and xlv.

‡ U. S. Geol. Exploration of the Fortieth Parallel (Fortieth Parallel Survey), vol. iii (1870), p. 451.

§ Fortieth Parallel Survey, vol. i (1878), p. 735.

‖ King: Fortieth Parallel Survey, loc. cit.

Western geologists have in general accepted the "faulted block" as the prevailing type of mountain structure in the Great basin, and the expression "Basin Range structure" has passed into familiar usage as a general designation of such type.

But recently an attempt has been made to overthrow these views,† and to prove that the ranges of the Great basin are not faulted blocks, but were formed as follows:

> "The process of mountain building in this region has been complicated, so it is to be expected that when the details shall have been more closely studied many types of ranges will be found. But at present we can hardly distinguish more than two—those formed chiefly by erosion and those due directly to deformation. To the first class seem to belong most of the mountains of the region. To the second class probably belong part of the ranges of two outlying provinces.‡ . . . The faults actually observed in this region are comparatively few. Actually ascertained heavy faults along the main fronts of ranges are exceedingly rare.§ . . . According to this conclusion these mountains are not simple in origin and structure. However, the writer would compare the typical Basin range to the less compressed portions of the Appalachians and the Alps." ‖

Besides the sweeping attack of Spurr just referred to, it may be noted that James D. Dana considered the fault hypothesis as not yet proved. He says: ¶

> "The *ridges* of the Great Basin, made thus of upturned and plicated rocks, have been assumed to be each limited by faults and to have undergone up and down movements and variously tilting displacements, and thus to have become in effect 'monoclinal orographic blocks' in the 'Basin System,'—each block making by itself a monoclinal mountain, even when not so in its bedding (Russell, 1885). In the ideal sections made to illustrate this hypothesis, the wide intervals of allu-

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*These views are explained rather fully and illustrated with several diagrams in Am. Jour. Sci., 3d ser., vol. 38, pp. 257-263, especially p. 259 et seq.

† Spurr: Bull. Geol. Soc. Am., 1901, vol. 12, pp. 217-270, pls. 20-25.

‡ Loc. cit., p. 241.

§ Idem, p. 259.

‖ Idem, p. 266.

¶ Manual of Geology, fourth edition, 1895, p. 366.

vium (that is, of buried and concealed rock) are represented as underlaid each by a block at lower level, or by the subterranean continuance of one sloping ridge to the next; and the actual flexures or lines of bedding have been omitted, and monoclinal lines substituted. They are intended to exhibit the supposed structure. But until the stratigraphy of the ridges of the whole basin shall have been studied and sections of them represented, and the relations of each ridge to those lying on the same northward or northwestward line of strike shall have been thoroughly investigated, general stratigraphic conclusions can not be safely drawn."

It would seem, then, that what is most needed is more information concerning the structural and other features of the individual ranges and valleys of the Basin region as a basis for the more general conclusions. In the present paper it is purposed to offer such information for a limited district in northwestern Nevada, the central geographic feature of which is the Humboldt Mountain range, and to draw from it conclusions as to the orogenic history of the district.

The Humboldt Lake Mountains

LOCATION AND EXTENT

The Humboldt range of mountains (the Koipato or West Humboldt range of the Fortieth Parallel Survey) lies in the western Basin region, in northwestern Nevada, some few miles west of the 118th meridian. As shown on accompanying map (plate 15), it is divided transversely into two parts, which are rather sharply separated by a considerable depression. The northern part, which may be called the Star Peak range,* runs almost due north and south for some 34 miles and reaches an altitude of 9,925 feet† in Star peak, 5,663 feet above Humboldt station. The southern part, which may be called the Humboldt Lake range, runs approximately northeast and southwest for about 42 miles and reaches the more moderate altitude of about 6,600 feet, or about 2,700 feet above the valley at Lovelock. The first part of the following discussion will deal with the southern range only, unless otherwise distinctly stated.

The rocks of the Humboldt Lake mountains fall naturally into two groups, which may be called, following the nomenclature adopted by the U. S. Geological Survey in the Sierra Nevada, the bedrock complex and the superjacent series.‡ These differ in age, origin, and structural relationships.

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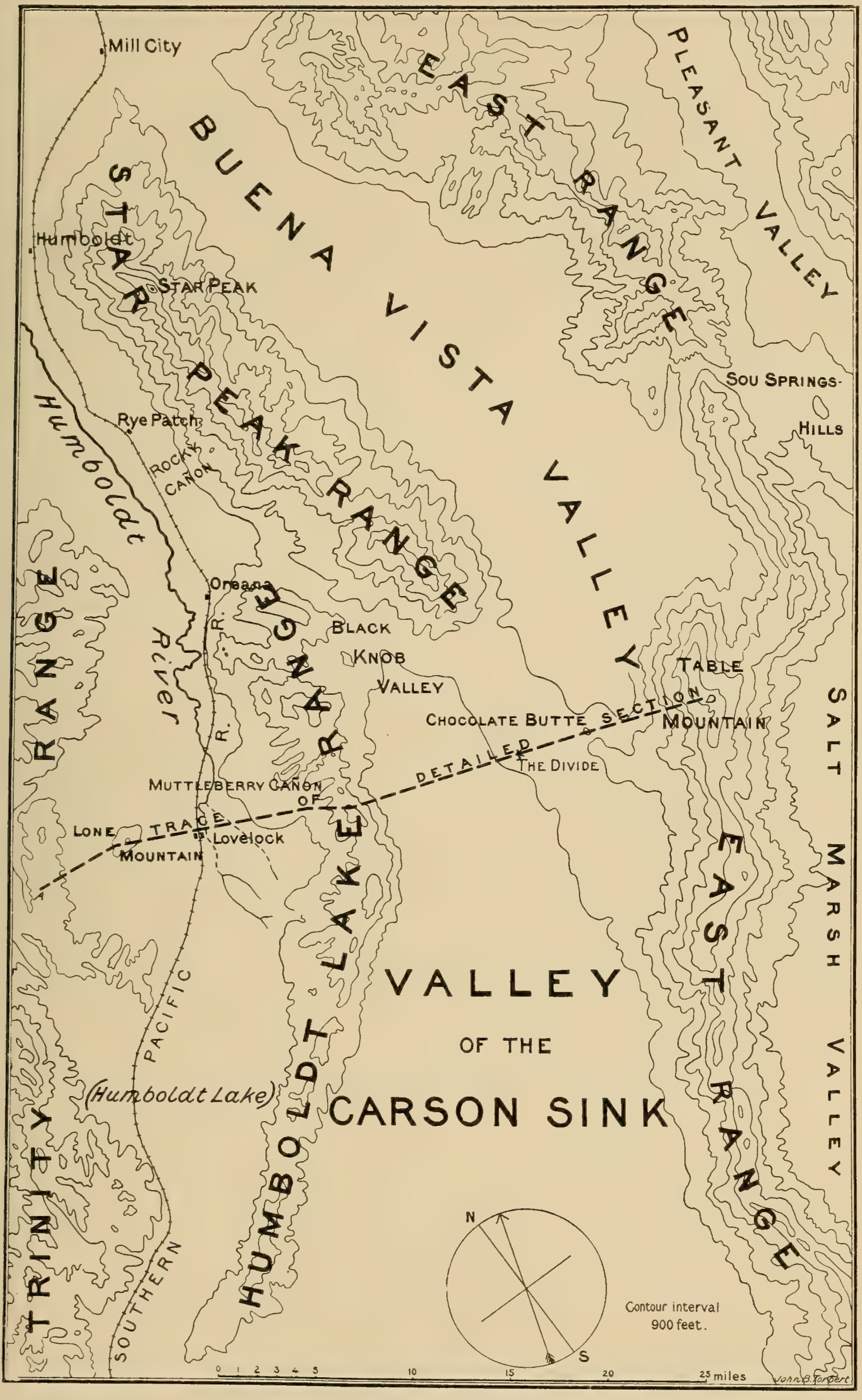
*See further on this point pp. 319 and 320.

†According to topography of Fortieth Parallel Survey.

‡The word series as used in this paper has no special technical stratigraphic significance, but applies merely to a succession of rock formations conveniently (and naturally) grouped together for the purposes of description and discussion. Complex seems to be a rather strong term for the bedrock of the Humboldt Lake range, but it seems desirable for purposes of comparison to use this expression, and the older rocks form quite a complex in some of the neighboring ranges.


Mill City
BUENA VISTA VALLEY
EAST RANGE
PLEASANT VALLEY
Humboldt
STAR PEAK RANGE
STAR PEAK
Rye Patch
ROCKY CAÑON
Humboldt River
TRINITY RANGE
Oreana
R. R.
HUMBOLDT LAKE RANGE
BLACK KNOB VALLEY
SOU SPRINGS HILLS
TABLE MOUNTAIN
SALT MARSH VALLEY
CHOCOLATE BUTTE
THE DIVIDE
MUTTLEBERRY CAÑON
LONE MOUNTAIN
Lovelock
TRACE OF DETAILED SECTION
EAST RANGE
VALLEY OF THE CARSON SINK
(Humboldt Lake)
SOUTHERN PACIFIC
N
S
Contour interval 900 feet.
0 1 2 3 4 5 10 15 20 25 miles
John B. Torbert

MAP OF HUMBOLDT REGION

THE BEDROCK COMPLEX

General composition and character.—The bedrock complex, so far as known, consists of marine sediments of Triassic or Jurassic age, with an occasional area of a granular intrusive. The rocks are, in general, folded, sometimes strongly plicated, faulted, and partially altered by dynamic action.

Lithological character.—The great bulk of the bedrock complex consists of marine sediments now in the form of shales or slates, limestones, and quartzites. The Triassic group consists chiefly of shale or slate and impure shaly gray or drab to black limestones, with here and there a thin layer of quartzite, which may, however, occasionally reach several hundred feet in thickness. Not infrequently a yellow or buff limestone occurs, carrying plentiful cubes of pyrite one-sixteenth to one-fourth inch on the edge. Gypsum appears irregularly, sometimes in thick lenses, as, for example, some 4 miles east of Lovelock, on the west flank of the range. Coarse oolitic and brecciated limestones occur to the southeast of Lovelock. Rarely a pure white marble can be found.

The Jurassic is chiefly gray to greenish gray slate, with subordinate limestone.

No attempt was made to measure the thickness of these groups of rocks, for in no place could they be seen in even approximately complete section. The Triassic is, however, much thicker than the Jurassic, and areally is much more important.

The rocks of the Humboldt Lake mountains are quite barren of fossils. Several fossiliferous horizons have, however, been found in Muttleberry canyon which allow of definite age determinations. The most abundant Triassic species is *Pseudomonotis subcircularis*, which is found either alone or associated with other forms. At the richest locality in Muttleberry canyon, Professor J. P. Smith has determined *Pseudomonotis subcircularis* Gabb, *Arcestes sp. nov.*, *Rhabdoceras russelli* Wyatt, *Placites, sp. nov.* and other characteristic forms. He considers them to indicate the Noric horizon of the Upper Trias. At the Muttleberry summit a limestone carries *Arietites sp. nov.* which Smith considers undoubted Jurassic. The Jurassic strata are apparently unconformable above the Triassic. These formations have been most thoroughly studied, however, in the northern part of the Star Peak group, where fossils are quite abundant. Triassic fossils were reported and described by the California Geological Survey and the Fortieth Parallel Survey, in the sixties and seventies. Recently the localities have been studied by Professor Smith as to their invertebrates, and Professor Merriam has collected and described good specimens of Ichthyopterygia. No Cretaceous or pre-Triassic fossils have been found either in the Humboldt range or in any range in its vicinity.

The character of the rocks of the Humboldt Lake range indicates, in general, comparatively shallow sea deposits. Pure limestones are rare and occur in thin layers. The most common type of limestone is argillaceous, and gray to black in color, but arenaceous limestones, limestone breccias,* limestones containing pebbles, oölitic limestones, gypsum, slates, and quartzites, all testify to the terrigenous or shallow water character of the greater part of the deposits.

Folding.—High angles of dip in various directions predominate in the bedrock complex. The major folds are generally open, but not symmetrical; the minor and subordinate folds are irregular, often overturned, and sometimes sheared.

The largest fold in the vicinity of the section studied is the Muttleberry anticline. Along the Muttleberry road this includes all of the exposed bedrock series. Near the mouth of the canyon at the west base of the mountains the slates give fine exposures, striking roughly along the range and dipping about 50 degrees west. Farther up the road are quartzites and fossiliferous limestones, varying somewhat in dip and in places corrugated, but with a decided general inclination to the west until near the summit of the road, when the dip flattens until almost horizontal. A short distance along the trail, east of the road summit, the rocks become vertical, and not far beyond are covered with later volcanics. They do not crop out again on the east side. Plate 16, figure 2, shows this anticline in section. The horizontal distance from its last western exposure to the axial line is about 2½ miles and the vertical distance 600 or 700 feet. It is distinctly unsymmetrical.

The Muttleberry anticlinal axis as it passes north trends somewhat eastward across the range, and a mile or two north of the canyon it is followed at the west by other folds. In a section passing through the gypsum deposits a couple of miles north of the mouth of Muttleberry canyon it is followed by a syncline and then another anticline.

The minor folds are more complex than the major one. At the gypsum deposits above referred to the southern part is folded into an unsymmetrical anticline, with its steep limb on the west. The northern part is folded into an unsymmetrical syncline, with its steep limb on the east. It has been brought approximately to the level of the southern anticline by a thrust.

An overturned and sharply bent fold is well exposed in Smith's wood canyon, just north of Muttleberry canyon.

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* This refers to limestones brecciated in original formation and not to those secondarily brecciated by pressure, as described on page 298.

An open cut at the gypsum quarry exposes a very complicated fold. It passes from the center of the top of the cut to the right (about 25 feet), then swings back in a low synclinal curve (some 35 feet), and finally passes down vertically (10 or 12 feet) and disappears beneath the floor of the cut. Furthermore, in this S-like fold the strata do not follow straight lines or simply flowing curves, but are highly crenulated and contorted. The details of the major fold show a great number of different types of folds, including closed, overturned, and carinate forms. Sheared forms are very rare and the amount of relative displacement in such cases is very slight. This is probably due to the flexibility of the gypsum, which makes up the greater part of the cut. There are, however, a few thin layers of limestone interstratified with the gypsum.

Faulting.—Faulting is rather common in the bedrock complex. The faults may be longitudinal or transverse to the range, normal or overthrust. The most common are the normal longitudinal faults. Such a one is represented in the detailed section (plate 21) on the west side of the Humboldt mountains, and will be more fully described later.

A striking example was found in the gypsum area already referred to. Looked at from the south, there appear to be two distinct beds of gypsum strongly marked by their white color against the setting of dark limestones and dull slates. There is, however, but one bed, which has been duplicated in exposure by a north-south fault along the strike.

This same gypsum bed is terminated at the south by a transverse fault which strikes about north 60 degrees east. This fault determines a canyon, the northwest side of which is made up largely of gypsum capped by black limestone dipping north, while the opposite slope contains no gypsum or black limestone, but is chiefly of slate, which dips south. The southeast country has dropped relatively to the northwest country not less than 200 feet, possibly much more.

Thrusting.—Thrusting has already been referred to in connection with folding, but one example will here be described a little more fully. North of the main gypsum anticline and separated from it by about three-tenths of a mile occurs a syncline of the same material, forming with its covering of black limestone a canoe-shaped structure, the east side of which is much steeper than the west. The south end has been lifted, so that it is about 200 feet higher than where the anticline passes down below the surface. The whole canoe is tilted along its axis, so that from its southmost point it pitches north, the axial inclination becoming less from south to north. In other words, the synclinal fold has been broken across the snout and thrust up over those rocks lying south and east of its original position, at least several hundred yards horizontally.

Alteration.—The rocks of the bedrock complex are all more or less altered. The silicious clastic rocks have all become quartzite, with no visible clastic structure. The purer limestones are all crystalline. The gypsum is all crystalline granular, although this may perhaps be an original structure. The argillaceous rocks seem to have suffered alteration, varying in intensity from place to place; but the results may subsequently be shown to be due to variations in original composition. Some of these rocks appear to be shales, finely laminated parallel to the bedding planes, often very friable and not notably altered in texture; but others have been distinctly metamorphosed by dynamic agencies and are now well developed slates. Slates are exposed in Muttleberry canyon near the spring, but still better in a canyon some three or four miles north of Muttleberry. The rock is quite hard, cleaves into large slabs, shows the cleavage and original laminations to be discordant, and has a luster on the cleavage face denoting a certain amount of recrystallization. Another peculiar slate, well exposed about a mile east of the gypsum deposit, breaks up into long thin rods up to 8 or 10 inches in length and rarely as much as a quarter of an inch through.

Another form of alteration is especially noticeable in the impure limestones. These, during the folding of the series, have been broken through by innumerable small fractures, which ramify into a fine-meshed network in the rock. The fractures have been subsequently filled with calcite, forming a network of white veinlets. The effect is striking when the white secondary calcite occurs in black limestone. The pure limestones do not show this brecciation.

This is not the only type of vein that intersects the bedrock complex. The slates and even the limestones are frequently traversed by quartz veins. These vary from thin stringers up to veins 5 or 6 and occasionally more inches across. Such veins have been noted at many places in the range, and while they sometimes contain considerable pyrite they are often of "barren" quartz. Nowhere in the southern range have they proved of any particular value, though in the Star Peak range there are many well known mining camps.

Barite veins have been found by the writer at two localities—one on the west slope, 12 miles south of Lovelock, and the other on the east slope, directly east of the same town. Fluorite was also found at the former locality.

Geomorphic relationships.—The effect of the bedrock complex on the topographic forms is frequently decided, although not great. Weathering generally produces rather smooth rounded forms, as is well shown in plate 17, figure 1. In other words, residual boulders, cliffs, crags, or other prominent forms are not generally produced. This applies particularly to the slate and limestone country, as a large mass of quartzite often stands out very ruggedly, its brown color and coarse angular talus frequently giving it the appearance in the distance of a massive lava.

The drainage lines are gullies and canyons which are commonly steep-sided and often very narrow and gorgelike just before their debouchment on the valley's edge. Higher up they may open out considerably into a blunt V-shape. There is a distinct tendency for the stream lines to become subsequent, but that character has been only partially developed. It is most noticeable in the intermediate and also the upper courses of the lower parts of the range, where the lateral branches frequently lie in strike gullies for comparatively long distances. The lower courses of all stream lines and the entire courses in the higher and steeper parts of the range are decidedly independent of the structure, lying nearly perpendicular to the present range front, whatever be the attitude of the rocks, and branching back like fingers from the main trunk. The mouth of Muttleberry canyon is somewhat exceptional in this regard, for as it comes down in the direction of the dip, though with a grade considerably less than the dip angle, it makes a sharp turn to the south for a couple of hundred yards and debouches on the valley along the strike.

Another form of stream topography is the fault-line gully or canyon. By this is meant any drainage line the two slopes of which are in faulted relationship with each other, the trace of the fault-plane approximately coinciding with the stream trace. The fault may have no other physiographic expression and is then determined solely by the lack of harmony of the strata of the two sides of the canyon. A half dozen of such occurrences were observed within a five-mile belt on the west slope of the mountains, two of which have already been described and illustrated under faults.*

Relation to range outline.—While the foregoing phenomena are of value with respect to the main problem before us, by far the most important geomorphic consideration is the relation of the form and topography of the range as a whole to the structure and attitude of the bedrock series.

The southern division of the Humboldt mountains forms a continuous range about 42 miles long. It rises out of a flat valley on either side, and, if we imagine the alluvial cones removed, its slope presents a practically continuous flowing curve as a trace upon the valley plane †—that is, there are no mountain lobes passing out into the valley, no bays or low, flat subordinate valleys passing into the range from the main valleys. The range, as viewed from the Humboldt valley, appears crescent-shaped, the concavity facing westward. The highest part is somewhat north of the center, and the ridge line pitches to the north and south until it passes underneath the valley in both directions.

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*See the longitudinal faults on detailed section, plate 21, and also the transverse fault described on page 297.

† The Lake Lahontan shorelines affect this appearance, in some degree, on the gentle slopes of the low parts of the range, but are everywhere quite easily eliminated from consideration.

As seen from the Muttleberry road, the range seems to have a simple anticlinal structure, the summit of the fold being close to the summit of the road; but northward from this summit the anticlinal axis passes east of the crest, and southward it passes west of the crest. To the north it is succeeded on the west by other folds, as described above, which, while they do not form a large angle with the range trend, are distinctly inclined to it. It follows that while the strike of the rocks is often parallel to the front of the range, yet it is frequently not so, and the result is that the folds have their axes directed obliquely toward the valley and are truncated by the plane of the primary valleyward slope. On account of the varying curves of fold axes and range front, some folds on the west side of the mountains* leave the range obliquely and are truncated on the northern end of their axes, as the gypsum syncline above described; others are cut on the southern end of their axes. The highest obliquity of strike to range trace was observed about 15 miles south of Lovelock, where a resistant stratum of limestone forms a small promontory on a Lahontan beach and strikes about north 82 degrees west, dipping south at a high and variable angle. The range trace here runs about northeast and southwest, and the limestone is obliquely intersected by the valley line.

In brief, the range shows a marked continuity of front, and the folds of the bedrock series, while elongated in the same general direction as the range, are distinctly discordant with it and vary in obliquity from 0 to 50 or 55 degrees.

Igneous rocks.—Igneous rocks associated with the bedrock series are not a prominent feature of the range; in fact, they hardly figure on the west slope at all. However, considerable diorite was encountered along the line of the detailed section, beginning near the summit, and exposed at intervals to a considerable distance down the east side. It is intrusive into the bedrock sedimentaries and underlies the superjacent series unconformably. Diabase boulders were also found in the Muttleberry alluvial cone. Granite, which occurs in all the surrounding ranges, including the Star Peak range, has not been found in the Humboldt Lake range.

Summary.—The bedrock complex consists principally of (Upper and Middle) Triassic and Jurassic marine sediments, invaded at some points by basic intrusives. It is universally folded, in places overturned and highly crumpled, and commonly faulted and even overthrust. A certain amount of metamorphism is prevalent. The axes of dislocation are rarely greatly but generally distinctly oblique to the range front.

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*There are practically none visible on the east slope, as will be seen later.

THE SUPERJACENT SERIES

General composition and character.—The superjacent series consists of freshwater sediments and of volcanic lavas and tuffs. The latter are distributed widely over the range, where they are sometimes quite thick, while in the valleys they are found only on occasional low hills or ridges. As will be shown later, they have proved of the greatest value in determining the nature and extent of the movements which have given rise to the Humboldt Lake range. The sediments—non-volcanic, lacustral, or fluviatile—are almost entirely confined to the intermontane valleys, and are of interest as possible indicators of the periods at which the various dynamic agents were active.

No marine sediments of later age than the Jurassic have ever been found in these mountains or in any of the surrounding country.

Sedimentary rocks—Truckee beds.—The presence of strata of the Truckee group was determined at the west base of the mountains, about 3 or 4 miles east of Lovelock, where they are exposed in a stream-cut in a terrace situated in front of the range. They consist of slightly consolidated granitic sands, diatomaceous earth, etcetera, and dip west at about 35 degrees. Basalt overlies them unconformably. There is a straight stretch of valley between them and the type locality at "Kawsoh" mountain. No other outcrops were met by the writer. They are, however, reported from the south end of the Star Peak range by the Fortieth Parallel Survey.

Lahontan beds.—Lake Lahontan* occupied the valleys on both sides of the Humboldt Lake mountains, and the shorelines are traceable without difficulty, and terraces, cliffs, tufa domes, pebbles on beaches, and other shore features are common. These phenomena are best developed and preserved where the mountains are low and with gentle slope; best developed because the work of littoral erosion was least burdensome; best preserved because the atmospheric and stream influences have been least active since the disappearance of the lake waters. On some low slopes, uncut by drainage lines, 6 or 7 fine long terraces with corresponding cliffs can be counted, and seem practically unaltered since they were deserted; but where the main stream lines pass into the valley, great alluvial cones, unnotched by any horizontal lines, extend out for hundreds of yards or for miles into the valley. Hard rocks, like basalt, preserve the shoreline traces beautifully, although the incisions are very shallow.

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*See also Russell: Monograph xi, U. S. Geol. Survey.

It is probable that both valleys are underlain throughout by the Lahontan sediments, but they have been covered over and hidden by the finer alluvial accumulations of Recent times. No stream exists in the valley to the east of the mountains which might lay them bare at some point, but in the Humboldt valley the river, opposite the northern end of the range near Oreana, has cut through 50 to 200 feet of the strata and given some fine sections. They are mainly unconsolidated and horizontally stratified sands. They evidently unconformably overlie the Truckee beds.

Alluvial and recent deposits.—The most important of these deposits are the great alluvial cones. The one encountered on the west side of the mountains in the detailed section is about 8,500 feet long, and rises 300 feet, with a slope of 1 in 28, or 2 degrees 4 minutes. On the east side of the range the section crosses one 7,000* feet long, which rises 350 feet, an average slope of 1 in 20, or 2 degrees 52 minutes. On approaching Table mountain, which rises 3,400 feet above the valley (the Humboldt mountains where crossed are only 2,100 feet), a cone was mounted which is 14,500 feet long and which rises 700 feet above the valley—that is, 1 foot in 20.5, or 2 degrees 46 minutes. The apex of the cone is taken in each case outside the general range slope and not within the canyon in which it rises. Some very fine material spreads itself out beyond the cones for quite a distance, but produces no appreciable slope, the valley being practically horizontal. As stated before, these cones are unmarked by sharp shorelines or other shore features, showing that at least all of the outer layers in all azimuths are post-Lahontan in origin. Distinct shore marks on the cones in other parts of the Lahontan basin, however, show that the bulk of each cone was formed in pre-Lahontan time.

In the lower part of the Humboldt valley the river has deposited 30 feet or more of alluvium, and the deposits in Humboldt lake, which now no longer exists, must also be considered Recent. No corresponding deposits occur in the streamless valley of the Carson sink, where Lahontan shore marks and tufa deposits can be seen still in the central parts of the valley floor.

The volcanic rocks—General character and relations.—The sedimentary rocks just described are essentially valley deposits, and, as far as known, nowhere occur on the mountains in question. The volcanics, on the other hand, occur chiefly on the mountains, where they cover large areas.

Volcanic rocks that are the successive products from several vents are likely to be very irregular in their areal distribution and order of superposition. The failure of a later to cover completely an earlier, or the overlapping of a later over an earlier, or the failure of a later to overlie an earlier at all, lead to some confusion, and make it difficult and sometimes impossible to arrange them in historic sequence. However, a complete series of the more important members seems to exist on the east side of the mountains just north and south of the Muttleberry road. Many other more or less complete occurrences have been observed, all of which agree with the order here given:

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*The section crosses this some distance below its apex; it is probably 8,000 feet long altogether.

Basalt (top of series).
Rhyolite tuff.
Rhyolite lava.
Rhyolite tuff (base).

Rhyolite tuffs.—The tuffs are generally white, sometimes brownish, mostly fine grained, and not particularly consolidated. Some layers are rich in glassy lapilli, others are highly pumiceous. No particular difference has been noticed between the tuffs above and those below the rhyolite lava. The most interesting features of the tuffs for the present purpose are those which point to their attitude of deposition. About half a mile south of the Muttleberry road, on the east slope, occur very good exposures of the tuff, in which were observed distinct current-bedded structures. Such layers contain small rock fragments up to ¼ inch or more in diameter scattered through them. The cross-bedding plains are irregular in their inclination to the true bedding and generally rather curved.

On the summit, about 2 miles north of the road summit, at the base of the tuffs, occurs a conglomerate of rather coarse pebbles up to 5 or 6 inches across and made up of quartzite, diorite, and other bedrock species.

The summit almost due east of Lovelock is of basalt overlying tuff. The contact is well exposed, showing a reddening of the topmost layers of the tuff and a roughening of the basalt bottom, which has been irregularly forced up and invaded, apparently, by steam generated by the action of heat on the moisture of the rock on which the basalt was poured. The layer on which the basalt rests is distinctly waterlaid and contains abundant small pebbles, chiefly of quartzite.

Across the Humboldt valley, just north of the west end of the detailed section, two layers of sandstone, one 6 inches thick, were found stratified in the tuff.

It may be added that all of the tuff is more or less distinctly stratified, but whether by water or air action is not always evident.

The above facts prove that at least part of the tuff series was waterlaid, and the evidence has been derived from the base, the top, and from several intermediate parts of the series. This means that these parts were deposited at a low angle, and, as the whole series shows angular consonance of bedding planes, the whole series must have been formed at a low angle—that is, approximately horizontal.*

Rhyolite lava.—Somewhere in the tuff series a flow of rhyolite is usually found. It is generally underlain by a considerable thickness of tuff, the greatest thickness measured in the vicinity being about 600 feet; the least, 6 or 8 feet. Where not overlain by basalt, the rhyolite is the top of the series and varies up to 200 or more feet in thickness; but wherever the basalt overlies the rhyolite, it is generally separated from it by tuff, from a few feet (10 or so) up to a few hundred. It is probable that the tuff has been removed from above the rhyolite by erosion wherever it was not protected by a basalt covering, and has also been removed entirely where neither basalt nor rhyolite has given it protection.

The rhyolite generally weathers buff or brown, but sometimes brick red. It is distinctly porphyritic, showing much feldspar and some quartz. The groundmass is generally lithoidal, but sometimes glassy, with various spherulitic and other structures. A good flow structure is common. In the Humboldt Lake range it is, so far as observed, conformably within the tuffs. In the Trinity range the tuffs have been found disturbed by tilting before the outpouring of the rhyolite.

Basalt.—Wherever found, the basalt is the youngest member of the volcanic series. It does not occur so extensively as the rhyolite in the Humboldt Lake mountains, being limited to a belt some 12 or 15 miles long near the north end of that mountain range, while the rhyolites are also extensively developed along the southern end of the range. It has overlapped the rhyolite in several places, however, and either lies over a comparatively thin tuff series, or may even lie directly on the bedrock.

Weathering has produced a dark brown or black film on most of the basalt, though a freshly broken piece is rather light colored and commonly a brownish gray. It the vicinity of the detailed section it is rather crystalline, and most of the groundmass can be resolved into its component minerals by the naked eye; in fact, it is quite doleritic. Near the upper surface of the flow it is commonly quite vesicular, but deeper in the mass the steamholes become smaller and fewer, from which we may conclude that the present surface is near the original surface of the flow. The cellules near the surface are frequently coated with a botryoidal opal (hyalite), and deeper in the flow they are sometimes entirely filled with calcite, though, as a rule, they are empty.

Wherever observed in these mountains, the basalt overlies the rest of

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*See also page 305.

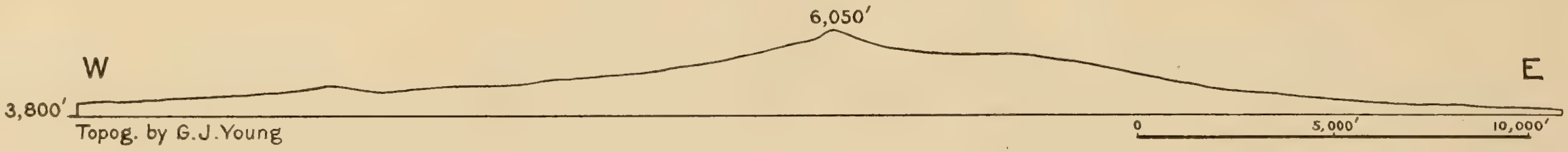
6,050′
W
E
3,800′
Topog. by G.J.Young
0
5,000′
10,000′

Figure 1.—Section of Humboldt Lake Range

Constructed from a series of points at intervals of 1,250 feet. Taken from measured section to show general effect of method of construction and of small scale

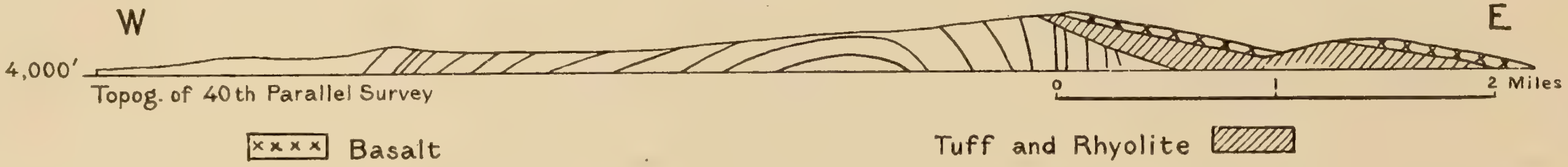
W
E
4,000′
Topog. of 40th Parallel Survey
0
1
2 Miles
× × × × Basalt
Tuff and Rhyolite ▨

Figure 2.—Muttleberry Canyon Section

Showing bedrock anticline and attitude of volcanics on east side. Geology sketched

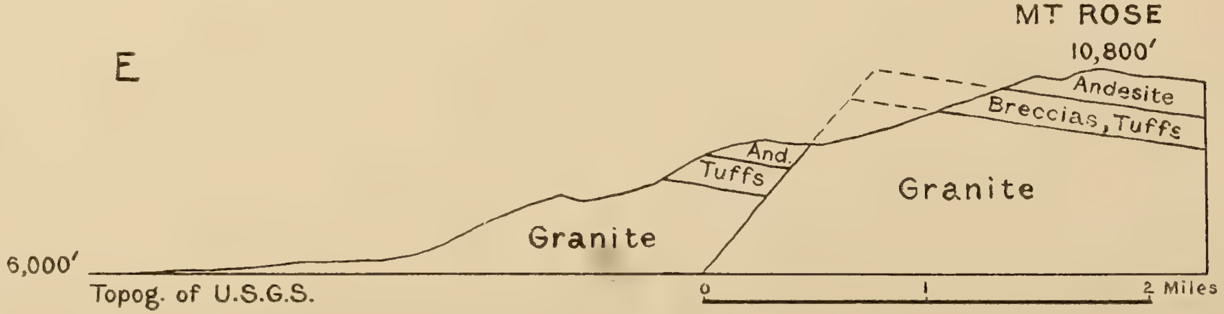
MT ROSE
10,800′
E
W
Andesite
Breccias, Tuffs
And.
Tuffs
Granite
Granite
6,000′
Topog. of U.S.G.S.
0
1
2 Miles

Figure 3.—Section East from mount Rose, Sierra Nevada, following Ridge Line

An example of secondary fault blocks, and also of the value of volcanics in determining the presence and extent of recent dislocations

SECTIONS IN THE HUMBOLDT REGION AND SIERRA NEVADA

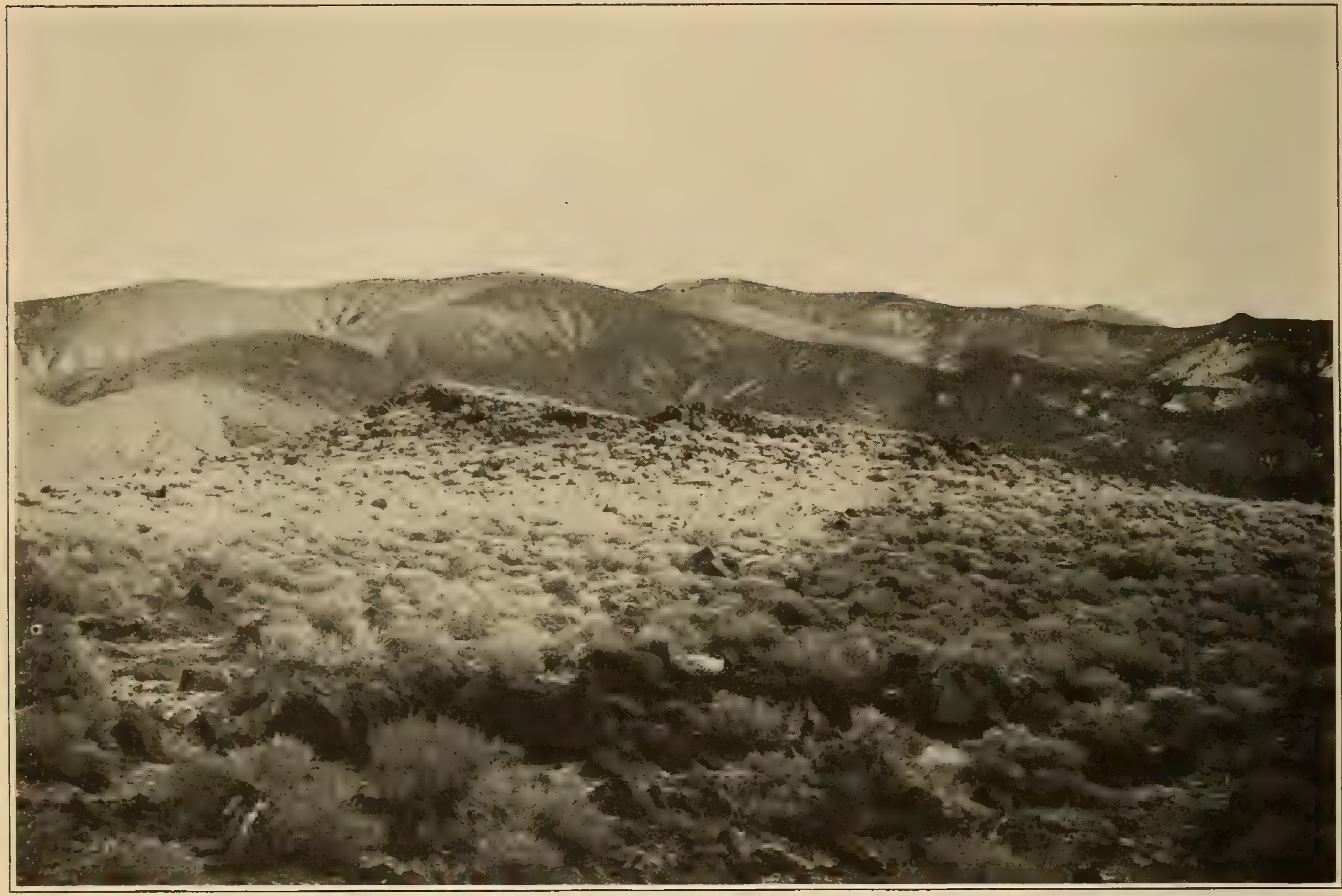

FIGURE 1.—BASALT AT WEST BASE OF HUMBOLDT LAKE RANGE

Smooth bedrock slopes shown in distance

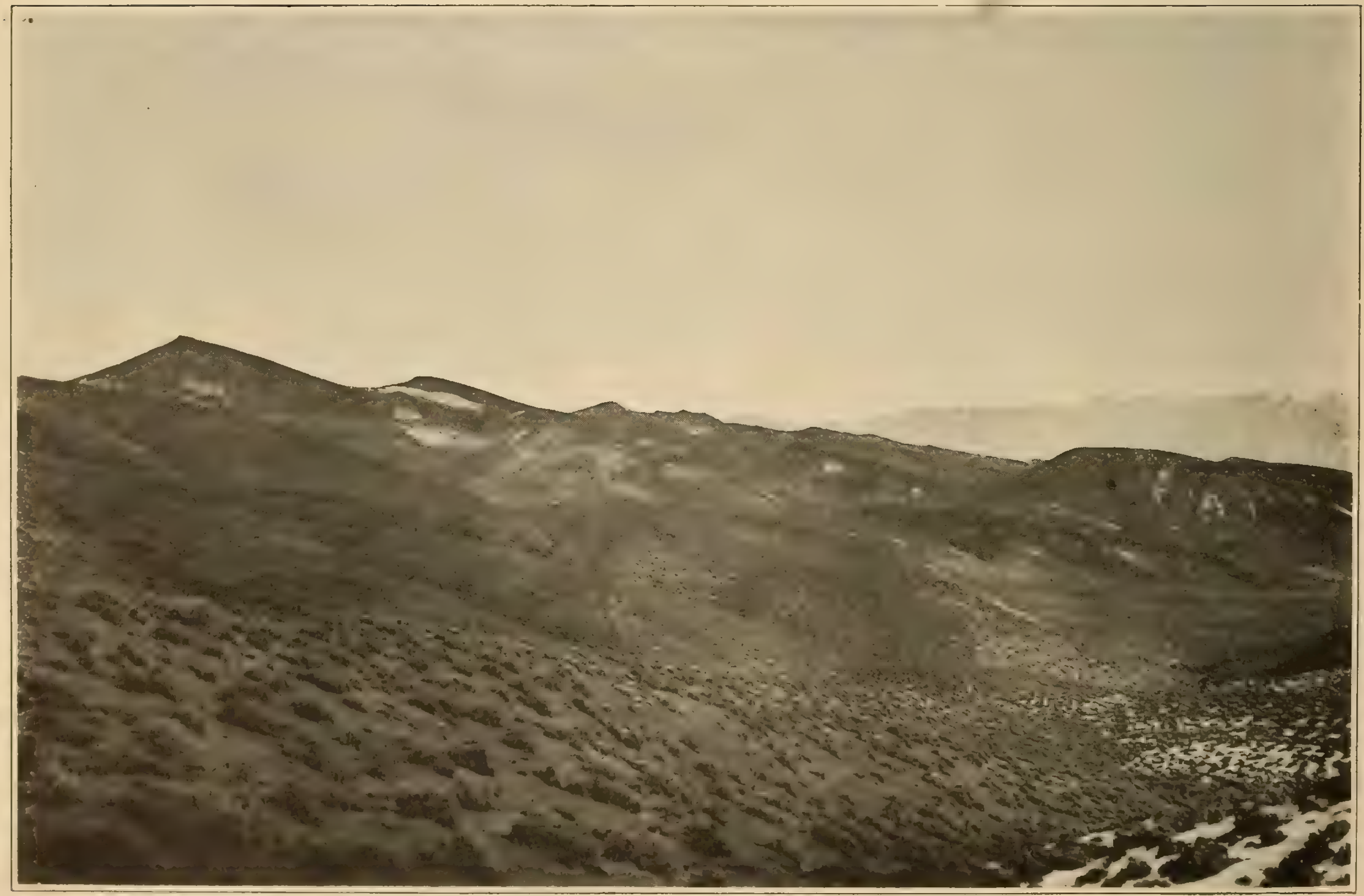

FIGURE 2.—VOLCANICS ON UPPER EAST SLOPE OF HUMBOLDT LAKE RANGE

Star Peak range in the distance

VOLCANICS OF HUMBOLDT LAKE RANGE

the volcanic series without any apparent angular unconformity. As might be expected, evidences of erosion between the rhyolite and basalt outpourings have been found.

The basalt offers us additional evidence of the low angle of the slope at which the series was formed. Following it north and south, or from crest to valley, we find great uniformity of thickness of the sheet. This could hardly have been the case if it had flowed down into the valley from the crest at its present altitude, or if it had encountered canyons or fair sized gullies on the mountain side.

Structure and distribution of the volcanics.—The volcanic series overlies unconformably the bedrock series. At several places angles of 20 degrees or less have been observed in the overlying basalt, where the bedrock slates dip at 88 to 90 degrees.

Nowhere are the volcanics folded or overthrust. They are affected by simple tilting, which may reach 45 degrees. The tuffs are not indurated, and none of the members are at all metamorphosed.* Faulting occurs, but it is always normal faulting, generally parallel to the range trend, more rarely transverse. Wherever it occurs the effect on the topography is direct, a more or less perfect scarp is always present, and the upthrown side forms the scarp. The only effect of erosion has been to change the slope or displace the front slightly or furrow the scarp with gullies. The flow of basalt on the top makes the recognition of the faults by stratigraphic discordance very simple, for the layer is broken along the fault plane, and, lying on the surface, abuts upon the scarp on the downthrown side and caps it on the upthrown block. When the whole volcanic series is present, the effect is more striking.

Examples of such faults showing simple fault scarps † or fault scarps only slightly affected by erosion may be seen in the detailed section carefully drawn to scale. Several can be seen in plate 17, figure 2, and a small but distinct one in plate 17, figure 1.

The distribution of the volcanic series is an important consideration in the present inquiry. Along the north-central part of the Humboldt Lake mountains—in other words, the highest part of the southern range—the volcanic series is entirely on the east side of the range. It reaches from the crest line, which it forms for a considerable distance, to the east base, where it dips down under the alluvium of the valley of Carson sink. Except where removed by the mountain streams in forming their canyons, or on the fault scarps as described above, the basalt forms the surface of the eastern mountain slope. Plate 17, figure 2, shows fairly the nature of the east side, all of the long eastward slopes being formed by the basalt flow. This is everywhere underlain by the tuff, which is, however, generally obscured by the black talus. Plate 18, figure 1, shows in the distance the even slope of the basalt down to and underneath the valley deposits. The underlying tuff can be made out at many places. The shadow in the foreground is of the crest line directly back of the observer and shows the characteristic slopes, the erosion cliff to the west, and the dip slope to the east. The structure is shown quite well in section, plate 16, figure 2.

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* This is not meant to include weathering, yet the tuff and lavas are not badly weathered. The feldspars are generally glassy, the pyroxenes and micas lustrous.

† "1. Where the fault has displaced the surface and the break remains undefaced or only slightly obscured, we may call the resulting cliff a simple fault scarp.

"2. Where erosion has acted unequally along a fault on account of the difference as to hardness between two rocks forced into juxtaposition or between a crushed zone and an intact one the resultant cliff may be termed an erosion fault scarp." Spurr: Bull. Geol. Soc. Am., vol. 12, pp. 258-259.

The slopes of basalt emerging from the valley and rising toward the crest of the range can be seen for 12 or 15 miles along the east side, but nowhere on the west slope has any basalt covering been found. At the north end and along the southern stretches of the range, where the mountains are low, the rhyolite passes over to the west side. In such places it covers the whole range from east to west, and presents cliffs to the west and long slopes to the east, corresponding to the plane of the tilted flows, even on the west edge.

Basalt has been found at the west base of the mountains just south and north of Muttleberry canyon. A short distance south of the mouth of the canyon a small hill (about half a mile wide) stands in front of, and apparently disconnected from, the range slope. It is composed entirely of basalt, very like that on the summit, which dips west at from 2 to 4 degrees.

Some distance north of the canyon, on a sort of terrace in front of the range, more basalt is found. It is identical with that on the summit in all its details, including the differences noticed in the different layers. It forms the surface of the terrace, except where obscured by alluvium, etcetera, and extends a mile or more north and south and about the same distance east and west. Plate 17, figure 1, shows a faulted portion of its east edge looking almost due east. It dips about 20 degrees south. In this plate the basalt-free slopes of the range are clearly shown. At its west edge the basalt is practically horizontal.

MOUNTAIN MOVEMENTS INDICATED BY THE VOLCANICS

Bearing in mind the facts already presented which indicate that the volcanic series was formed at a low angle of inclination to the horizontal plane, the simplicity of its structure and the exceedingly slight amount of alteration of its members should afford us easily decipherable evidence of post-volcanic earth movements that have affected the range.

If, in order to get an idea of the topography at the time the basalts were poured out, we imagine the dip of the inclined volcanic series to decrease until the angle becomes very low, the associated bedrock being necessarily depressed to the same extent, the elevation of the range as a whole would diminish with the decreasing angle of dip, and as this latter approached the horizontal the range as a topographic feature would approach extinction.

An examination of the base on which the volcanics were deposited shows a remarkable absence of relief. Where the basalt lies directly on the bedrock its upper and lower surfaces are at many observed localities practically parallel planes, and the same may be said of the tuffs, although the base of these has been observed at but three or four places. The volcanic series may be traced for many miles on the east side without encountering any bedrock ridges or other projecting forms protruding through them to the surface. However, gentle broad rises and depressions can be made out at some places, which have influenced the thickness of the volcanics or the distribution of the flows. Judging from this latter evidence alone, we must conclude that the relief of the pre-volcanic topography of the range was very low and at many places closely approximated a plain. No pre-volcanic canyons filled with tuff or lava have yet been observed. In other words, the erosion period represented by the pronounced unconformity between the bedrock and the superjacent volcanic series had produced a country of very low relief, approaching, to say the least, a peneplain condition.

What is the nature of the process by which the mountains were brought to their present condition and attitude? Two possible explanations of the uplifting of the range suggest themselves—anticlinal folding and faulting with tilting.

Let us first examine the fault hypothesis. As just shown, we may infer, in the vicinity of the detailed section before the deformation of the basalt flows, the existence of a country of very low relief, covered widely by a volcanic series, the highest member of which was an approximately flat-lying basalt flow. This may be represented roughly by the diagrammatic east-west section (figure 1).

If, now, faulting be supposed to occur along a plane whose trace is marked *A B* (figure 1), the eastern block rising with tilting, the western block subsiding, there results a condition represented in section by figure 2. This section, however, possesses the essential characteristics of a section of the present Humboldt Lake range, the lava-free western slope showing exposures of folded bedrock and the simply tilted volcanic covering of the eastern slope. Other peculiarities of the Humboldt range are readily explainable as incidental to such a process. For example, the occurrence of irregular areas of basalt along the west base could be accounted for by some irregularity in the settling of the valley block, whereby it is traversed by smaller faults breaking it here and there into secondary blocks. The visible basalt lies on small secondary blocks that have lagged behind, while that associated with the main valley block has been covered and concealed by lake beds and alluvium. Subsidiary faulting might be expected in the mountain block also, where it would break the basalt flow into parts that would be displaced with respect to each other. Such changes are represented in figure 3, with which may be compared the actually observed condition in the Humboldt Lake range, as shown in the detailed section.

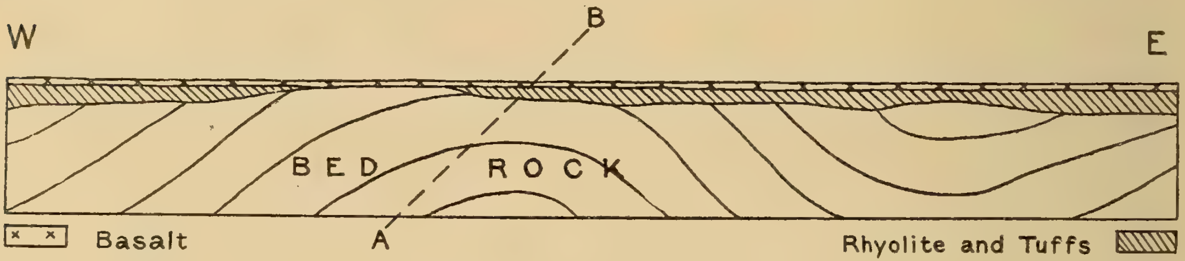

FIGURE 1.—*Structural Features.*

Diagrammatic east-west section to illustrate the chief structural features in the vicinity of the detailed section at the time of the outpouring of the basalt. Tertiary lake beds and slight irregularity of lower surface of basalt not represented. The bedrock structure is typical, not representing any particular section.

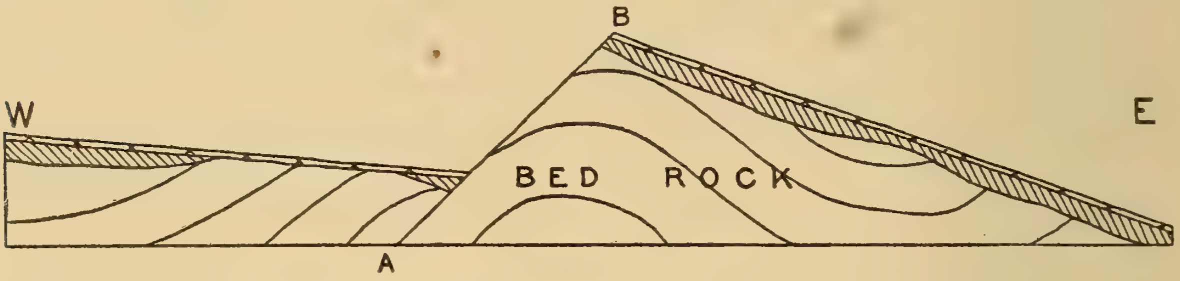

FIGURE 2.—*Simple Faulting.*

Diagram illustrating a possible result of simple faulting with tilting along the line *A B* of the country represented by figure 1.

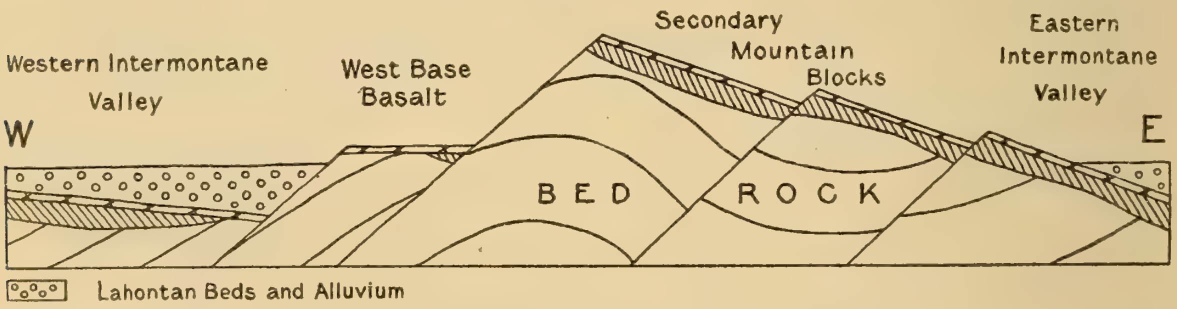
Western Intermontane Valley
West Base Basalt
Secondary Mountain Blocks
Eastern Intermontane Valley
W
E
BED ROCK
Lahontan Beds and Alluvium

FIGURE 3.—*Formation of Minor Structural Features.*

Diagram illustrating the inferred mode of formation of the more important minor structural features of the Humboldt Lake range as a simple modification of figure 2. The valleys are represented filled with alluvium and Quaternary, which hide any basalt that may exist on the sunken blocks. The effect of erosion on the fault-scarps and the existence of alluvial cones is not represented, but the transition is easy from this diagram to the detailed section (plate 21) of the Humboldt range.

Such a fault hypothesis therefore, without any unusual assumption, satisfactorily explains the structural characteristics of the Humboldt Lake range, which may be summed up as follows:

1. The presence of the basalt (and other volcanics) on the eastward slope of the range for some 12 to 15 miles, the bedding planes forming essentially the topographic slope.
2. The extension of this basalt from the summit to the east base of the range along which it dips regularly underneath the more recent valley deposits.
3. The absence of volcanic flows and tuffs on the westward slope of the range.
4. The occurrence of irregular flat-lying or very low-dipping* patches of basalt along the west base of the range.
5. The normal longitudinal faulting of the eastward dipping beds.

By an anticlinal fold theory it would be very difficult to explain the entire absence of the basalt from the west slope, considering its peculiar attitude and extent on the east slope and at the west base, and where the basalt is found at the west base, its lack of any marked westward dip is unaccountable. Furthermore, on the east side we find simple tilting without folding combined with subsidiary normal faulting (as suspected for the valley block), which denotes extension rather than lateral compression, the necessary concomitant of folding.

If this explanation of the structure by faulting and tilting is true, the west base basalt is part of the same flow which covers the east slope, and the rocks should be petrographically very similar. It is worth while, then, to examine the petrographical details of the rocks from both sides.

PETROGRAPHICAL DESCRIPTIONS AND COMPARISONS OF SUMMIT AND WEST BASE BASALTS

General characteristics.—In general appearance the rocks look very much alike. The general description has already been given. The upper part of each is rather vesicular, and this character gradually decreases with depth, showing that in both the surface is near the original flow surface. Crystallization is complete, and a hand specimen shows a mottled appearance due to the alternations of dark and light minerals. No compact black basalt has been found in either of these localities.

Microscopical physiography of Summit rock.—The rock just south of the Muttleberry summit is holocrystalline, with no distinct separation of any of the minerals into two generations, except that a large feldspar is occasionally seen, which may be considered a phenocryst.

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* Flat-lying or low-dipping with regard to an east-west section. One part of the larger area dips south. The smaller area, south of Muttleberry, has a west dip, but not half that of the mountain slope.

The feldspar occurs in moderately small laths, .1 to .5 millimeter, rarely .6 to .7 millimeter, and generally shows simple albite twinning, although not infrequently crystals with four or more alternations can be found. Careful examination by the statistical method showed a maximum extinction angle, in symmetrically extinguishing twins, of 35 degrees (another 34 degrees), corresponding to a medium labradorite. Zonal structure is rare, and shows only three or four layers. Two Carlsbad twins were seen with halves twinned according to the albite law.

Olivine is rather abundant and occurs in grains of varying size from .2 to 1 millimeter, with intermediate gradations. Some of the grains show a partial development of crystal planes. When fresh it is a very pale green, almost colorless, but is universally stained yellow or reddish brown on the edges, or along cracks, frequently throughout the whole mass. In general, the grains are traversed by irregular cracks, but a few show both pinacoidal cleavages—(010) and (100). Extinction is straight, and the optic axial plane is perpendicular to the cleavages. The maximum birefringence is about .035 and refractive index high. In general, it appears to have formed earlier than the feldspar, though occasionally laths of the latter were found penetrating the olivine.

The pyroxene is of a peculiar pale grayish brown color (quite unlike the ochreous or reddish brown of the olivine) and shows a good cleavage. Its grains are rather small and are interstitial as regards the feldspar, and therefore xenomorphic. It is not pleochroic, has a high refractive index, and a maximum birefringence of about .020. High extinction angles were measured up to about 40 degrees. It is evidently augite.

Magnetite in cubes and grains or in crystalline aggregates in the form of strings or masses is quite abundant. It does not occur in a fine dust. It is included in such a way by the feldspars, etcetera, that it appears to have been the first mineral separated from the magma.

With the exception of the stained olivines, there is practically no decomposition of the rock except on the very surface.

There is a rather distinct flow arrangement, especially of the feldspars, and these latter include between them the augite in small, irregular, grain-like, or elongated anhedrons. The rock, in short, is an olivine dolerite, with a fine grained diabasic structure showing a fluxional arrangement of the particles.

Another Summit rock.—About a mile north of the above described rock specimens were taken which answer the same description throughout except that larger laths, which show a zonal structure, are considerably more abundant.

West Base basalt.—In megascopic characters this rock, which occurs a mile or more north of the mouth of Muttleberry canyon, is very like the summit rocks, except that the feldspars are more easily discernible.

The feldspar occurs in laths, which are in general somewhat coarser than those in either of the summit rocks. A maximum extinction angle of 33 degrees was observed, which corresponds to a labradorite of about the same composition. With the larger laths the polysynthetic character of the twinning is much more marked, eight or ten alternations being not uncommon, and zonal structure is also more frequent. Small feldspars also occur and there are all intermediate sizes. In other words, two distinct generations can not be made out.

The olivine is pale green and partly automorphic. It is stained yellow to reddish brown, especially along cracks through the grains. The grains occasionally show the pinacoidal cleavage with axial plane perpendicular to both. The maximum birefringence is about .035, and the refractive index is high.

The pyroxene is in larger grains than in the summit rocks, but it has the same peculiar pale grayish brown color. It has a good pyroxene prismatic cleavage and a high refractive index. The extinction angles up to 34 degrees were measured, and a maximum birefringence of about .021. The grains are almost entirely xenomorphic. It is evidently an augite very similar to the summit augites.

Magnetite occurs in cubes, grains, or elongated aggregates, and is evidently the oldest separation from the magma, as it is included by the other minerals. In structure the rock is holocrystalline, but, unlike the summit rocks, it shows only an imperfect fluidal orientation of the feldspar laths. The augite occurs in distinct angular wedges between the feldspar laths, and in many cases larger augite masses were seen to wrap about the ends of the feldspar in true ophitic fashion. The rock is an olivine dolerite with a diabasic structure only slightly affected by flow.

Another West Base rock.—About half a mile south of the mouth of Muttleberry canyon is a basalt hill. On the lower slopes the rock is brown and has a different appearance in the field from the basalts in general; but microscopic analysis shows that it is made up of the same minerals in practically the same proportions and with the same structures, the coarseness of grain and appearance of flow being intermediate between the above described summit and base specimens. The olivines, however, are all weathered and stained reddish brown throughout, which probably accounts for the difference in general megascopic appearance.

Résumé of petrographical study.—Microscopical petrographical study shows that the summit and base rocks are made up of the same minerals, showing in detail the same optical peculiarities and with essentially the same structures, the only difference being a slight one in the size of the grain and the greater or less influence of fluxional movement, both non-essential variations.

Basic dikes.—At several points on the lower part of the western slope basic dikes were found, running roughly parallel to the range trend. They are black and granular on fresh fracture, and weather with a thick limonite film. In the field it was suspected that they were the feeders of the basalt flows and had been truncated by the fault plane. Under the microscope they are seen to be quite fresh basaltic rocks, made up of a holocrystalline aggregate of basic plagioclase, augite, and magnetite. The last two are more abundant than in the basalts above described, but olivine was not recognized in the sections examined.

SUMMARY OF STRATIGRAPHIC EVIDENCE OF FAULTING

It has been shown that the structure of the folded, faulted, and partly altered bedrock series is distinctly out of consonance with the trend and form of the range, and that its mass was degraded to low relief before the eruption of the volcanics. These volcanics were laid down at a low angle, and their deformation is approximately a measure of the deformation of the rocks of the range in post-basaltic times. The occupation of the whole east slope from summit to base for many miles by the volcanics, together with their entire absence from the west slope and the occurrence of rocks of almost identical mineralogical and structural features at the west base of the range, all of them being affected by simple tilting, combined with normal faulting, is all easily explained by faulting along the west base and a lifting and tilting of the range toward the east, the west slope being the eroded remains of the fault scarp. None of the distinctive features can be explained by anticlinal uplift.

PHYSIOGRAPHIC EVIDENCE OF FAULTING

Relationship of structure to range lines and fronts.—Lack of dependence between ridge lines and associated tectonic features, and continuity of range front irrespective of the parallelism or obliquity of rock structures, form an important criterion of dominant lateral faulting in mountain upheavals. This was in part first stated by Gilbert in giving his generalizations on the Basin Range structure, as follows: *

> "Furthermore, ridge lines are more persistent than structures. In the same continuous ridge are monoclinals with opposed dip, as in the Timpahute, Pahranagat, and House ranges—or monoclinal and anticlinal, as in the Spring Mountain and Snake ranges."

Recently W. M. Davis, in critically discussing the argument and conclusions in Spurr's paper on "The Origin and Structure of the Basin

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* U. S. Geog. Survey West of the 100th Meridian, vol. iii, p. 41.

Ranges,"* expressed† in concise and clear form two physiographic criteria for range origin by faulting. He says:

> "In the first place, the structure of the ranges is commonly oblique to their border, so that the faulted margin passes indifferently from one structure to another, as in the accompanying figure; if the ranges were the residuals of a long period of undisturbed erosion, such a lack of correlation between border and structure would not be looked for; but if the ranges are limited by faults at one side or both, the indifference of border to structure is natural enough."

These two statements taken together present fairly what we may call the first physiographic criterion of a "fault-block" range—the principle of the unity of the range as an elevated mass and the persistence of ridge line and range front in the face of discordant and varying structures. No further presentation or explanation of the principle seems called for. It is evident that in mountains of the Appalachian type (ranges of folding, whether modified or not by erosion) no such phenomenon can be observed.

In discussing the bedrock complex, especially under the title "Relation to Range Outline,"‡ the relationship of the structure to the range form of the southern group of the Humboldt mountains was described in some detail. We may sum it up by saying that the range shows a marked continuity of crest and front, the former passing over various structures, while the folds of the bedrock complex are distinctly discordant with the front and vary in obliquity to it from 0 to 50 or 55 degrees. As far as this test is concerned, the range corresponds to a faulted block.

The test of erosion forms.—Again Davis says: §

> "In the second place, the body of each range is usually continuous, although it may be incised by sharp-cut valleys; if the ranges were the residuals of a period of undisturbed erosion long enough to have permitted the excavation of broad intermont valley-lowlands, each range should be divided into isolated mountain groups by the opening of wide branch-valleys in its mass; but if the depressions and the ranges are blocked out by recent faulting, the continuity of the ranges is to be expected."

Reference to the detailed section will show that the broad intermontane valleys are from two to three times as wide as the ranges. If these broad basins were cut out by stream corrasion and general erosion there should be, as stated above, broad valley arms extending into or completely through the ranges, and broad, low, flat strike valleys (subsequent valleys) within the ranges themselves. No approximations to such valleys are found. The range is, as already described, a unit, with a sharply defined marginal line, which runs in flowing curves; no ridge arms pass out into the valley, no valley lobes run into the range. The second physiographic test, then, holds for this range.

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* Loc. cit.

† Science, n. s., vol. xiv, p. 458, September, 1901.

‡ See page 299.

§ Science, n. s., xiv, 459. See also Gilbert, U. S. Geog. Survey West of the 100th Meridian, vol. iii, p. 41.

But there are other sculptural features which give confirmatory evidence of the general fault origin and also add details to the history.

Evidence from stream valleys.—If the intermontane valleys had been formed by erosion or had been for any considerable time secondary base levels for the streams flowing from the mountains, these streams would have followed the usual fluvial-physiographic cycle, and while still vigorously cutting downward along their upper stretches and producing sharp V-shaped canyons, at their mouths or junctions with the valleys, they would broaden their channels and produce, at least on a small scale, a flood or laterally cut plain, while the canyon would open into an obtuse V. In this connection the west slope (presumably the fault-scarp side), which, where the range is highest, is made up entirely of the bedrock complex, is the more interesting. We find here the conditions just the reverse of these described. The waterways, which usually run at right angles to the mountain front, are generally narrow and gorge-like near their mouths. Along the middle slopes of the mountains, however, they open out and show a tendency to adjust themselves to lines of strike.* These gullies are, of course, everywhere cut in bedrock.

This open and partially subsequent character of the streamways of the middle and upper mountain slopes and the gorge-like and unadjusted character along the lower slopes may be explained by the fault hypothesis if we consider the movement to have taken place gradually or in stages. The streams along the lower slopes are, then, flowing over more recently exposed ground, exerting all their energies in downward cutting, while the atmospheric and other agencies of general erosion have not had time to widen the canyons. The upper stretches have been longer exposed, and, although the streams are now cutting downward, the agencies of general erosion have had a longer time to act and subsequent tendencies have been developed, perhaps at some period of comparative rest. It is hard to see how any folding or erosion hypothesis can explain these drainage characters.

On the east slope, as might be expected, very little information can be obtained on this point. The trunk drainage lines are in general perpendicular to the uplift, but longitudinal valleys are common. While these are strike valleys as regards the volcanic series, they are truly consequent in nature, for their positions have been determined directly by the topographic slopes due to faulting, as shown in figure 4. The stream flows in the angle between the fault scarp and the surface of the dropped block. The fact that a friable tuff is encountered under the basalt makes cutting rapid and easy.

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*This is described more fully under "geomorphic relationships," p. 298.

Another prominent feature of the mountain canyons is their real "hanging" character with respect to the intermontane valleys. They debouch at from three to seven hundred feet above the valley, which they reach by a long alluvial cone. This means that throughout the life of the mountain streams corrasion has not been active enough in the valley to cut away the alluvial cones or to allow the mountain streams to cut down to the level of the valley. That there were not original conditions of active corrasion, followed by choking of the streams and raising of their levels, is proved by the fact that they lie in bedrock bare of detritus, except a thin film in or near the present channel. Their channels have in no case been built up from a former lower position.

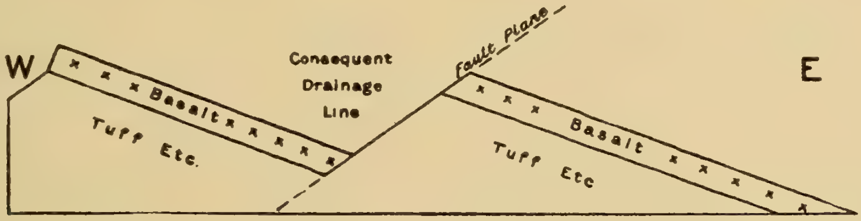

Figure 4.—*Consequent Stream Valley formed by Faulting.*

Evidence from basalt and erosion.—In a previous discussion it was stated that erosion alone could not produce the distribution of the basalt which we actually find. Some further consideration of this may be of value. The west side is the side that has no basalt covering, though several large patches occur at the west base, while the east side is covered from summit to base; but the western valley is only two-thirds the width of the eastern valley. It would seem remarkable on any erosion hypothesis that erosion should be so much greater on the side of the smaller valley. On the side of the broader valley the basalt, which, as has been already shown by lithological evidence, is probably but slightly eroded by general agencies, passes down with the same appearance and thickness underneath the valley alluvium, and this for several miles along the range, except where cut by outflowing transverse streams. In other words, on the edge of a valley some 75,000 feet wide there has been no visible action referable to the lateral corrasion of a valley stream on the surface layer of the mountains. It should be added that no evidence has been found, either on the mountains or at their base, of a higher layer than the basalt. This evidently means that there has been no corrasion along the mountain flanks in post-basaltic times.

After the outpouring of the basalt and the upheaval of the mountains, the first event of which we have evidence in the valleys is the formation of alluvial cones, then the deposition of Lake Lahontan sediments, following which comes the desiccation of the basin and the further deposition of alluvium by the river or mountain streams. In other words, after the deposition and deformation of the basalt the broad intermontane valleys, far from showing great erosion, have been continuously up to the present day basins of deposition.

Evidence from the basalt is by no means so complete on the west base, but the occurrence of even these smaller areas shows that no extensive corrasion, such as would have cut out the west valley and have determined the west slope, can have taken place, and the fact is that the mountain slope passes down below the west base basalts, and from this slope the basalts extend west either at a low angle (south of the road) or horizontally (north of the road) from a half to one mile. Evidently the west slope was not determined by any post-basaltic corrasion.

SUMMARY

The writer has sought to present all the observed phenomena which bear on the question of the origin of the Humboldt Lake range of the Humboldt mountains. The characters of the orogenic movements have been determined by the following relationships:

1. The nature, attitude, and distribution of the volcanic series.
2. The independence of structure on the one hand and range line and front on the other.
3. The general character of erosion forms.
4. The special character of the mountain stream valleys.
5. The relation of the basalt to erosion.

All of these tests are in consonance with an origin by faulting; none of them are compatible with an anticlinal uplift and erosion. We may conclude, therefore, that the territory now occupied by the Humboldt Lake mountains, at some post-Jurassic time previous to the formation of the volcanic series, was in a condition of very low relief. After the outpouring of the basalt this territory was relatively uplifted with respect to the present valleys, with faulting along its west margin and tilting toward the east, thus producing the Humboldt Lake Mountain range. Since the inception of the orogenic movements, the relatively depressed areas—the valleys—have been basins of deposition, and the mountain flanks have suffered from no corrasion due to intermontane valley streams.

NEIGHBORING AREAS

APPLICATION OF PREVIOUS INVESTIGATIONS

For the southern group of the Humboldt mountains the description, discussion, and tests applied have been presented in considerable detail. With these facts and conclusions in mind we may examine some of the neighboring uplifts. If these present a general analogy to the range studied, and if one or more of the criteria of faulting apply, we may be satisfied as to their history and origin without as complete and detailed a study as was given the first range.

STAR PEAK RANGE

The bedrock complex.—The Star Peak range has already been referred to as the northern division of the Humboldt mountains, which is separated from the southern division by a transverse valley. It is considerably higher than the southern division, although not so long.

The bedrock complex of this range is composed of practically the same horizons as in the range already discussed. Indeed, paleontologic evidence of the age of the various members is much more abundant. According to Professor J. P. Smith, the limestones of the Star Peak range belong to two different horizons, the lower, in Star canyon, being Middle Trias, the upper massive limestone being Upper Trias. The most diagnostic forms he finds in the Middle Trias are: *Analcites whitneyi* Gabb, *Beyrichites rotelliformis* Meek, *Ceratites nevadensis* Mojsisovics, *Ceratites* (*Gymnotoceras*) *blakei* Gabb, *Sageceras gabbi* Mojsisovics, *Joannites gabbi* Meek, *Daonella dubia* Gabb.

There are also many new species not yet described. Characteristic Upper Triassic and Jurassic forms have already been given in speaking of the bedrock complex of the Humboldt Lake range. Furthermore, Doctor Smith has been unable to find any fossils below the Middle Trias or above the Lower Jura (Lias) in either the Star Peak or the Humboldt Lake range.

It may be said that, allowing for a certain amount of variation, the bedrock complex of the Star Peak range is very similar lithologically to that of the Humboldt Lake range. It consists of Triassic and Jurassic marine sediments associated with various igneous rocks. These sediments are folded, faulted, somewhat metamorphosed, and intruded, as described for the other range.

The granite and time of its intrusion.—No exposure of granite was found in the Humboldt Lake mountains, but a considerable area is exposed on the west slope near the southern end of the Star Peak range. This locality was visited to determine, if possible, the relation of the granite to the Mesozoic sediments. Rocky canyon is the easiest place to reach the granite. After climbing a long alluvial cone, the granite is met about half a mile within the true canyon, the western flank of the range being made up of bedrock sediments, chiefly limestones.

The rock that lies next to the granite, where the contact was studied, is a kalksilicate-hornfels, which is banded and carries some carbonate. It is only about 50 feet thick, and may be traced into a perfectly conformable series of well stratified drab to pale gray limestone, partially recrystallized. These dip some 66 to 70 degrees west for a hundred yards or so, where after a slight contortion the dip flattens.

The occurrence of the calcite-limesilicate hornfels on the contact, followed by partially crystalline conformable argillaceous limestones, is in itself, ordinarily, sufficient evidence of the intrusive character of the granite. For completeness the following may be added:

The contact is quite irregular.

Separated chunks of hornfels were found imbedded in the granite in two places.

The hornfels carries thin granitic dikes up to several inches in width, which are also found directed outward in the granite near the contact.

The bordering limestones have steepest dip near the granite, and their dip becomes less as they are farther and farther away.

The Fortieth Parallel Survey geologists who considered the granite Archean and thought that the Triassic lay unconformably over the granite, explained the steepening of the dip by thrust of the limestone against the unyielding granite mass. They also apparently observed the granitic dikes without recognizing their significance:

> "In the limestones in the region of Wright's canyon* and the large canyon to the north, are irregular veins of feldspar, with occasional but rare masses of milky white quartz."†

The granitic dikes are made up of quartz and orthoclase, with no muscovite or ferromagnesian mineral visible to the naked eye.

Time of granitic intrusion.—The granite is thus proved to be post-Triassic, but it has not yet been found in contact with Jurassic sediments. The fact that the bedrock complex was greatly folded as a whole at the end of the Jurassic period, the Triassic having been not greatly disturbed before the deposition of the Jurassic, would make the post-Jurassic period of folding the most natural time for the granite intrusions. This also corresponds to the period of great granitic intrusions throughout the Cordilleran region wherever definitely determined.*

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* Now called Rocky canyon in Lovelock.

† Hague: Fortieth Parallel Survey, vol. ii, p. 719.

The superjacent volcanics.—The occurrence of members of the superjacent volcanic series appears to be greatly restricted in the Star Peak range. Only one area of basalt has been observed, but this occurs in a significant position. Near the south end on the east side a sheet of basalt, sloping with the hill slope—that is, forming the surface layer—rises from the broad valley east of the range and extends almost to the summit at that point. No faults can be seen to break its slope. On the west side no volcanics make their appearance. Passing still farther west, we meet the east slope of the Humboldt Lake mountains with their eastward dipping basalt passing down underneath the valley detritus, while the west slope contains none. This is exactly what we would expect if the Star Peak range, like the Humboldt Lake range, had been elevated by faulting and tilting, the fault plane running along the west basal margin and determining the transverse valley separating the two mountain ranges. The west slope of the valley would then be the natural slope of the tilted surface of the Humboldt Lake range; the east slope the eroded fault scarp of the Star Peak range.

Structural and physiographic discordance.—The unity of the range front and ridge line and their indifference to rock structures is as marked in this as in the southern range. A glance at the Fortieth Parallel Survey map also makes it at once evident.

Erosion features.—The erosion features are very similar to those of the southern range, except that, as the range is considerably higher, the forms are more rugged and the relief more sharp. Absolutely no trace of lowland valley lobes or low, flat internal strike valleys can be found and no mountain projections into the broad intermontane valleys. The streams run in narrow canyons, especially sharply V-shaped at their lower ends, and debouch on the valleys through bedrock channels at several hundred feet above the valley floor, which they reach by great alluvial cones.

Conclusions.—We may conclude, then, that the Star Peak range of mountains has experienced practically the same history as the Humboldt Lake range; that after the post-Jurassic folding a long period of erosion ensued. Just what the character of the relief was throughout the range at the time of the outpouring of the basalt has not been investigated, but where the basalt flowed it must have been very low. Following the period of volcanic activity, the range was uplifted by relative

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*See Lindgren: U. S. Geol. Survey, Geologic Atlas, folio 66, Colfax, California.
Ransome: U. S. Geol. Survey, Geologic Atlas, folio 63, Mother Lode district, California.
Lawson: Journal of Geology, vol. i, p. 579.
Also Turner, Fairbanks, Whitney, and others.

elevation along a fault plane at its present west margin, with tilting to the east. This fault plane extended south and passed through Black Knob valley, curving to the east around the southern end of the range, making of the Star Peak range a crust block separate from and independent of the crust block which produced the Humboldt Lake range. The nearness of approach of these two blocks is a most interesting feature. It has led to the single name Humboldt range, which has been given to the two together, although the break is distinct and the ridge lines are independent. Instead of being roughly continuous, the two range lines overlap in a north and south direction, the Star Peak mountain ridge line running south until, descending, it passes into the intermontane valley of the Carson sink some miles east of the Humboldt Lake range, the Humboldt Lake mountain ridge line running north until, descending, it passes into the intermontane valley of the Humboldt some miles west of the Star Peak range. The Star Peak division of the Humboldt range is geologically more closely related to the low divide which separates the valley of Carson sink from Buena Vista valley, and which will be described later, than to the Humboldt Lake division. In this paper, therefore, the two divisions have been called the Star Peak range and the Humboldt Lake range respectively.

Mountain profile.—Viewed from the top of Chocolate butte, in the valley to the south, the Star Peak mountains show a beautifully regular profile, with a long, gentle slope to the east and a distinctly shorter, steeper slope to the west. Such characteristic profiles have been used frequently, it is believed, as indications, perhaps by some as proofs, of the tilted fault-block character of various ranges. This characteristic has not been used here as an element of the proof in any discussion because of its imputed abuse. " Indeed," says Spurr,* " as in so many other cases, the existence of the fault seems to have been assumed from the presence of a scarp." The regularity and expressiveness of the profile in this case has induced the writer to at least call attention to its existence.

The great transverse valley.—An explanation has already been given of the transverse valley which separates the Star Peak from the Humboldt Lake mountains, but further discussion is desirable. Spurr,† speaking of the valley, says:

> "The existence of the latter fault is evident from an inspection of the map accompanying the Fortieth Parallel report. Judging from this, the displacement seems to be a downthrow on the south side, bringing the Star Peak Triassic down against the underlying Koipato Triassic—a movement amounting to several thou-

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* Bull. Geol. Soc. Am., vol. 12, p. 226.

† Bull. Geol. Soc. Am., vol. 12, p. 225. His discussion is based on the Fortieth Parallel Survey Report.

sand feet. The fault line lies in the valley, from which the mountains rise on the southeast* side about 2,700 feet, on the northeast side about 4,200 feet. The southeast or downthrown side of this valley is decidedly the steeper.

"In this case we have an actually determined† fault which is not marked by a scarp, but by a transverse valley, where erosion has excavated at least 2,700 feet deeper than in the rocks on each side; nor is this more than a fraction of the total erosion, for while the valley was being formed the mountains have also been steadily wearing down, only more slowly, on account of the zone of greater weakness along the fault. On the northeast all the Star Peak Triassic (which is now found on the other side of the fault, and so must have been on this side, too, before the dislocation) has been worn away, leaving bare the underlying Koipato. As the Star Peak group has an estimated thickness of 10,000 feet,‡ the total erosion since the faulting has at some points exceeded 2 vertical miles. The present greater elevation of the mountains in the upthrown or northeast side of the fault is probably due to the greater resistance to erosion of the Koipato quartzites as compared with the softer rocks on the south.

"In the West Humboldt range, therefore, there is evidence of erosion powerful enough to have determined the topography and the range itself, and in the one case where we are sure of our premises, erosion has long since overcome all direct effects of deformation on the surface, if, indeed, there ever were any."

The southern part of the west slope of the transverse valley is covered with the basalt and underlying volcanics before described. Evidence has been presented to show that these volcanic rocks were formed at a low angle § and have been tilted into their present attitude during the upheaval of the range. In plate 18, figure 1, the snow-tipped range in the distance is the southern part of the Star Peak range. The southern portion of the transverse valley which separates the ranges can be seen with the basalts and their underlying tuffs dipping down at the valley margin underneath the valley deposits. In other words, since the tilting of the volcanic series there has been no corrasion along the southwestern valley margin. The sense of the faulting indicated by the volcanics and by physiographic evidence is the same as that given by Spurr; that is, the northeast side has been elevated relatively to the southwest side. The higher mountains on the northeast are not, however, due to rocks more resistent to erosion, but to a greater throw on the Star Peak Mountains fault than on the Humboldt Lake Mountains fault. This difference is characteristic of the two ranges throughout, even though the Star Peak and Koipato groups, including both hard and soft rocks, are found about equally distributed in both. The very culminating point of the range—Star Peak—the highest mountain in the vicinity, is made up of "Star

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* This should be southwest; probably a typographical error.

† Spurr uses this expression, "actually determined fault," for one determined on the evidence of stratigraphic discordance.

‡ It was not estimated in the vicinity of this point, however.

§ See pages 303 and 305.

Peak Triassic," the formation so easily, according to the account quoted, removed by erosion.

That great erosion has occurred in the bedrock series there is ample proof, but it was evidently chiefly during the interval between the post-Jurassic folding and the laying down of the volcanic series over a country of low relief. The post-basaltic erosion of the intermontane valleys is practically nil, and the erosion within the mountains, judged from its effects on the volcanic series, has not proceeded very far.

Recent faulting.—Faulting of the Recent period has been frequently reported in the Basin region, and Russell presents a map * showing the lines along which he has determined Recent fault scarps. The best example of such faulting found during the present investigations is along the west base of the Star Peak mountain block. A very distinct scarp was traced for 6 or 8 miles, and, according to Russell, it continues along the whole length of the range. It varies in height from 4 or 5 up to 30 or 40 feet, depending apparently on topographic slope, character of rock, etcetera. This fault scarp presents a striking contrast with the Lahontan shore cliffs which are so common in that part of the Great basin, for while the horizontal base line of the shore cliffs winds about projections or into recesses, the fault scarp climbs up over the alluvial slopes and drops down into the intervening hollows. No deposits are too late for it to traverse, and even the alluvial cone coming from Rocky canyon, which is one of the larger drainage lines, shows the fault scarp, here several feet in height, running across its apex. Plate 18, figure 2, is a view of the Star Peak range looking southeast from the alluvial cone of Rocky canyon. The fault scarp can be traced quite distinctly along the base of the range for almost a mile.

Such recent faults may be considered evidence that the old fault planes are still planes of weakness, and that the great crust blocks have not yet perhaps reached their final condition of equilibrium. Such planes are evidently possible loci for future movements.

TABLE MOUNTAIN AND THE EAST RANGE

Location and extent.—The Table Mountain or East range (the Pah Ute range of the Fortieth Parallel Survey) is the first range east of the Humboldt mountains. It is a rather long and high range, and for the present purpose was studied only in the vicinity of Table mountain, a flat-topped, basalt covered portion about 30 miles east of Lovelock.

The bedrock complex.—The character of the bedrock complex is so similar to that in the Humboldt mountains that, for the present purpose, it needs but slight notice. Nothing distinctly Jurassic was observed. The

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* U. S. Geol. Survey, Monograph xi, plate xliv.

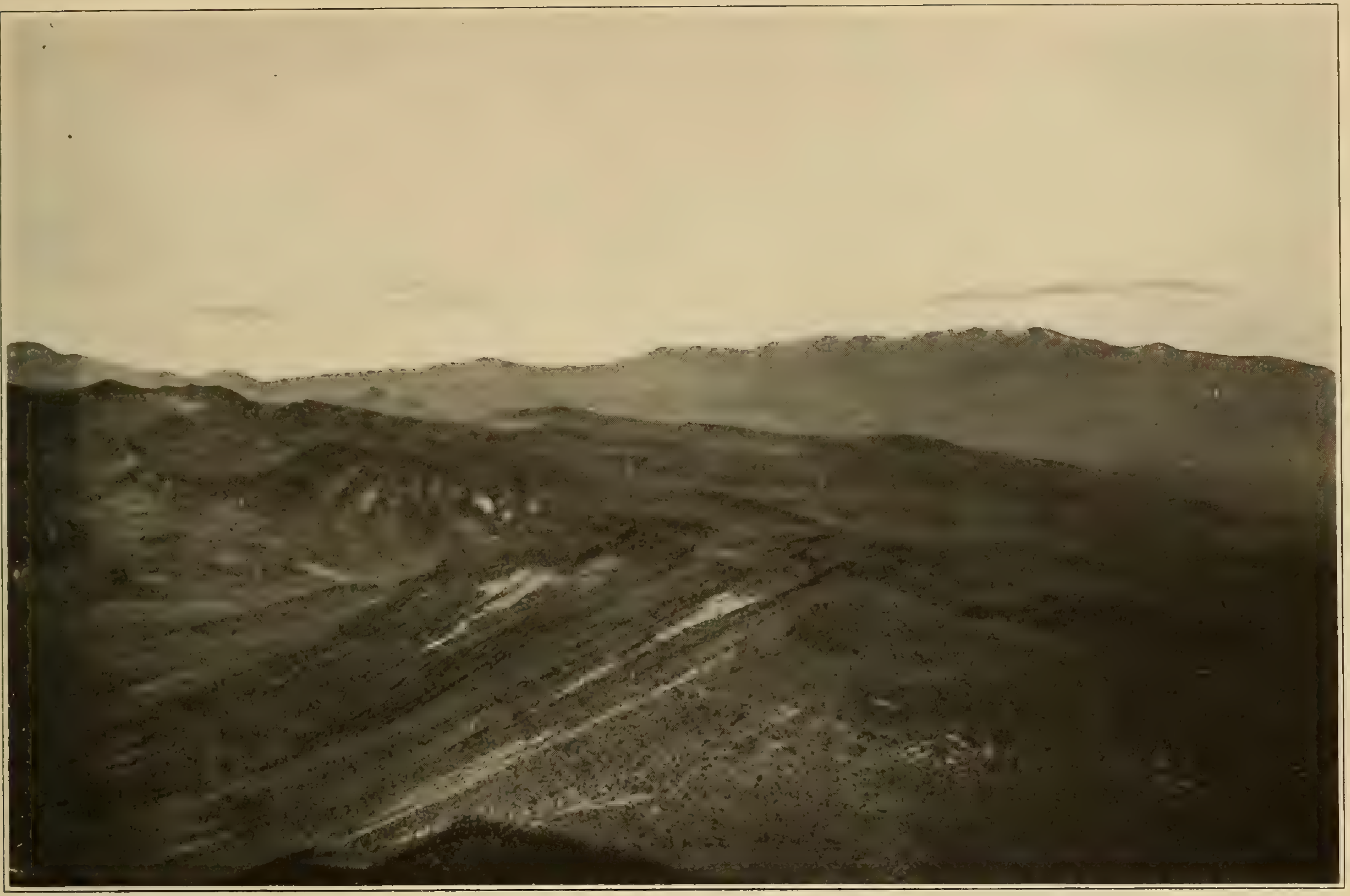

Figure 1.—Volcanics on lower East Slope of Humboldt Lake Range

Illustrating how basalt and other volcanics dip into valley. Black Knob valley and south end Star Peak range in distance

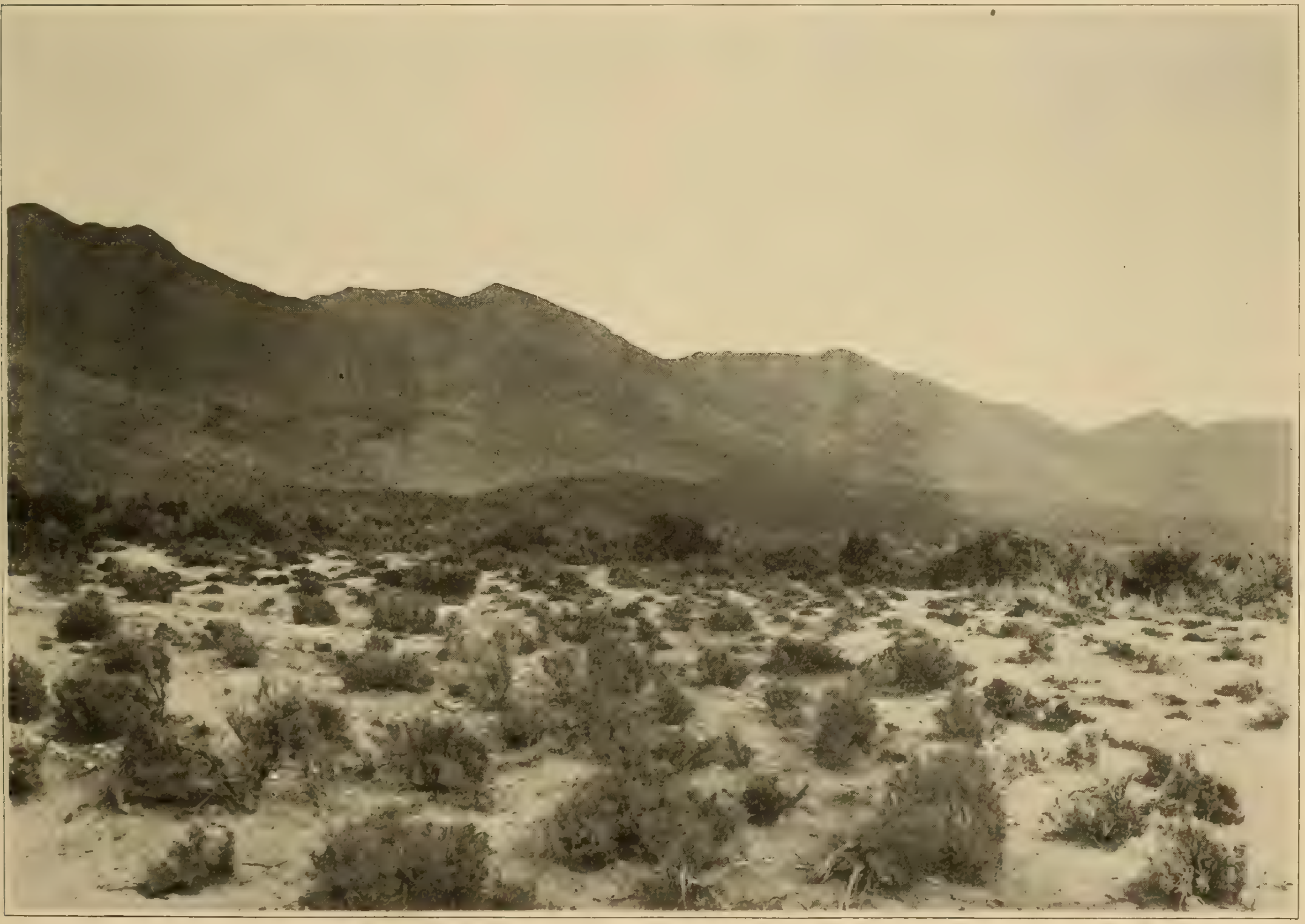

Figure 2.—Recent Fault Scarp on West Side Star Peak Range

View taken from alluvial cone heading in Rocky canyon

VOLCANICS OF HUMBOLDT LAKE RANGE AND FAULT SCARP IN STAR PEAK RANGE

Triassic occurs as slates, limestones, and quartzites of characteristic appearance. Igneous intrusives are more common than in the Humboldt ranges, and include coarse diorites and granites. Folding, faulting, and alteration of the bedrock complex are everywhere observable.

The superjacent volcanics.—Neither flank of Table mountain carries basalt, or any other member of the volcanic series inclined so as to form the hill slope as on the east side of the Humboldt Lake range. In fact, the flanks are of bedrock, while the top carries basalt, in a number of layers, underlain in part, at least, by other members of the volcanic series. The true state of affairs is misrepresented in the atlas of the Fortieth Parallel Survey, where the basalt of Table mountain is made to occupy the whole slope down into and along the floor of the valley through a vertical range of 3,400 feet. From the mapping, one would conceive of the basalt as flowing out of some elevated vent, after the formation of the range, pouring down the sides 3,400 feet, and then flowing out over the valley floor.

Hypothesis of upheaval.—Reasoning by analogy for the purpose of getting a working hypothesis, which may be tested later, we may consider the volcanics of Table mountain the equivalents of the volcanics of the Humboldt mountains, laid down at the end of the great period of erosion and before the uplift of the Humboldt range. If the Table Mountain range suffered an upheaval analogous to that of the Humboldt range after the outpouring of the basalt, this must have been brought about by lateral faulting on both sides, with relative elevation of the range mass as a whole, with slight and unessential tilting, as shown in the diagram.

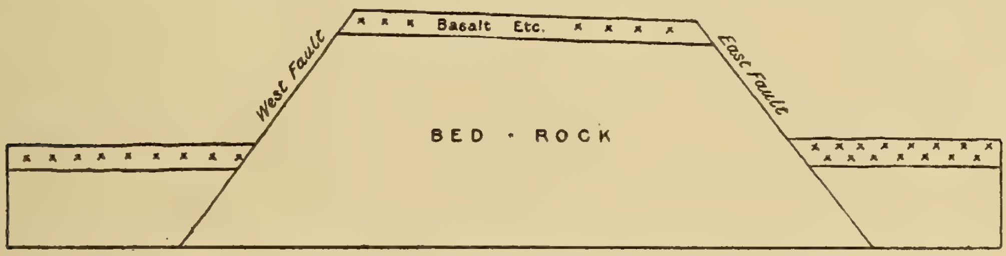

FIGURE 5.—*Diagram illustrating the essential Character of Table Mountain Faulting.*

Test of volcanic distribution.—Character of the proof. If such upheaval, with but slight tilting, is the true history of Table mountain, we may hope to find basalt in the valley on the west side lying above the level of the alluvial filling because of uneven settling of the valley floor. That is, the valley block might be intersected by minor faults and thus broken into secondary blocks, as we have seen is probably true of the Humboldt Valley block, and as is distinctly the case in the Humboldt Range block, and also, it may be added, in the Table Mountain block. Fortunately, we do find basalt in the valley, and its occurrence will be presently described.

Occurrence of secondary blocks.—But, first, it would be well to show that Table mountain is broken by minor faults into secondary blocks. Standing on the top of the "table" and following the basalt flats with the eye, one is immediately struck by the fact that there is not one single uniform table, but several. One table will spread out for a quarter or a half or even a whole mile, and then suddenly end in a drop or rise leading to another table. In other words, the general tableland is broken up into a number of secondary plane surfaced tables, which are separated by sharp vertical breaks or by erosion channels. They do not flow into one another by lava cascades; the result is due to normal faulting.

Basalt in the valley of Carson sink.—About two-sevenths the distance from the western base of Table mountain to the Humboldt Lake range a line of hills rises out of the alluvium of the intermontane valley and runs for some miles at a small angle to the front of the East range. A general east-west profile across the summit of the most northern of these hills is given in the detailed section. It rises about 850 feet above the surrounding valley floor. In structure it is a miniature of the Humboldt Lake range. It is capped by basalt, which passes, though somewhat broken by normal faulting, from the summit to the east base and is absent from the west slope. The basalt is underlain by tuff, and this by rhyolite lava, all dipping east. Where crossed by the detailed section the bedrock does not appear at the surface, but half a mile south the volcanic series is seen to be underlain by quartzite, diorite, etcetera, striking north and south and dipping high to the west.

The divide.—About 3½ miles west of the base of these hills a low divide occurs. This low, flat ridge, though only 150 feet above the valley bottom where crossed by the detailed section and probably only 100 feet where crossed by the wagon road, separates completely Buena Vista valley from the valley of Carson sink. It runs from the south end of the Star Peak range southward, diagonally across the valley, toward the East range. It is in part capped by basalt, but where crossed by the detailed section the bedrock reaches the surface. The basalt is flat-lying over the greatly eroded and planed surface of the bedrock complex.

It may be here pointed out that the report of the Fortieth Parallel Survey gives a wrong idea of this basalt-covered divide and one quite out of consonance with the general conceptions presented in this paper. Referring to this ridge, it says: *

> "It is of considerable interest, as it forms a divide across the valley, completely shutting in the Carson and Humboldt desert to the south, and is one of the few prominent cross-ridges of Tertiary eruptive masses connecting the longitudinal ranges of the basin."

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* Fortieth Parallel Survey Report, vol. ii, p. 704.

The idea given by the statement and its context is that the divide is a line of volcanic vents or of lava flows. The fact is the ridge is essentially a bedrock ridge, with merely a covering of lava, just like the ridge farther east already described. On this divide the lava is thin, and the bedrock, where crossed by the detailed section, rises 150 feet above the valley deposits to the west.

The basalt province.—If, now, reference is made to plate 15 of the general map and the distribution of the basalt as a whole considered, the argument for each of the ranges is strengthened by the consideration of the whole region. The areas discussed form a moderate-sized province, with the same characteristics throughout, and with sufficient outcrops in the valley region to refer the different exposed masses to the same event. The west base and east side of the Humboldt Lake range, the southeast part of the Star Peak range, the ridge extending across the valley from Star peak toward the East range, the higher valley ridge east of this, and finally Table mountain, all are similarly covered with basalt, which generally lies over tuffs or leveled bedrock, with no indications of vents. It may be horizontal or tilted, but not folded, is affected by normal faulting, later than the great post-Jurassic erosion period and earlier than the Lahontan deposits and shorelines, never badly weathered; in fact, almost always exceedingly fresh, notwithstanding its unprotected surface position and easily alterable mineral composition. It is especially fortunate that in the region studied, which is so characteristic in its stratigraphic relations, structure, and lithological nature, no other basic volcanics are found beside this one basalt.

East side of Table mountain.—It may be added that similar basalts occur in the valley on the east side of the East range, although not down the east slope, as in the Humboldt Lake mountains. They were not studied in the present investigations, but the lithological similarity of the basalt in the divide above described and that on the east base is noted in the Fortieth Parallel Survey Report.*

Results of study of the volcanics.—The conclusion would seem to be warranted that the Table Mountain region and the adjoining valleys were part of the surface of low relief recognized for the Humboldt Mountain area, which was produced by the long post-Jurassic erosion and on which were laid the various members of the volcanic series, particularly the easily traceable basalt; that these areas were contemporaneously subjected to orogenic deformation of the same character; that the mass of the Table Mountain range was elevated with respect to the east and west bordering areas as a massive block along fault planes on both sides of the range, with some shattering into secondary blocks along minor fault planes and with but very slight tilting. The relatively depressed blocks, which have formed the lateral valleys, also settled, with some slight breaking into secondary blocks, two of the more elevated of which, in the western intermontane valley, now rise as low basalt-covered bedrock ridges above the lake beds and alluvium of the valley bottom.

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* Vol. ii, p. 704.

Physiographic tests—Form and structure.—If the above conclusions are true, the East range must stand the test of the physiographic criteria of faulting. The East or Table Mountain range presents a unity such as we have described for the other ranges. It rises sharply and distinctly from the surrounding flat valleys, with a simple marginal trace and ridge line. These features are distinctly unrelated to the structure of the bedrock series. The front of the range where met by the detailed section runs 30 or 40 degrees east of north, the slates 5 degrees west of north. Not quite half way up the range the rocks swing around and run northwest and southeast, dipping southwest. This attitude was traced across several canyons (perhaps a mile or more). These and other discordances and variations are not represented in the topography at all. A glance at the general features of the Fortieth Parallel Survey atlas shows distinctly the lack of relationship between structures and either margin or ridge line.

Erosion features.—Where examined, the East range shows almost no tendency toward the formation of subsequent drainage features. The canyons head back at a high angle to the front of the range, with very little curvature or sinuosity, toward the crest. Throughout their courses they pass parallel or perpendicular or at any other angle to the strike of the rocks indifferently. As in the Star Peak range, this character of drainage, as compared with the incipient subsequent character in the Humboldt Lake range, is probably due to the altitude of the range—that is, to the magnitude of the uplift—the continued elevation preventing the drainage from becoming adjusted to the structural and lithologic conditions of the bedrock.

No bay- or gulf-like extensions of the valley floor are yet indicated in barest infancy, and no intramontane valleys, subsequent and low, are to be found. Everything points to recent uplift, the erosion forms being not only unadjusted, but in their youth from source to mouth. Where crossed by the detailed section one of the larger channels leaves the mountains 650 feet above the valley floor, and reaches the valley along a cone over 14,000 feet in radius. It is highly improbable that erosion sufficient to have carved out the surrounding valleys could leave the range in such a youthful condition in its physiographic cycle.

The flat table tops unbroken except by faulting, and the basalt dipping down underneath the valley on the east side of the first western

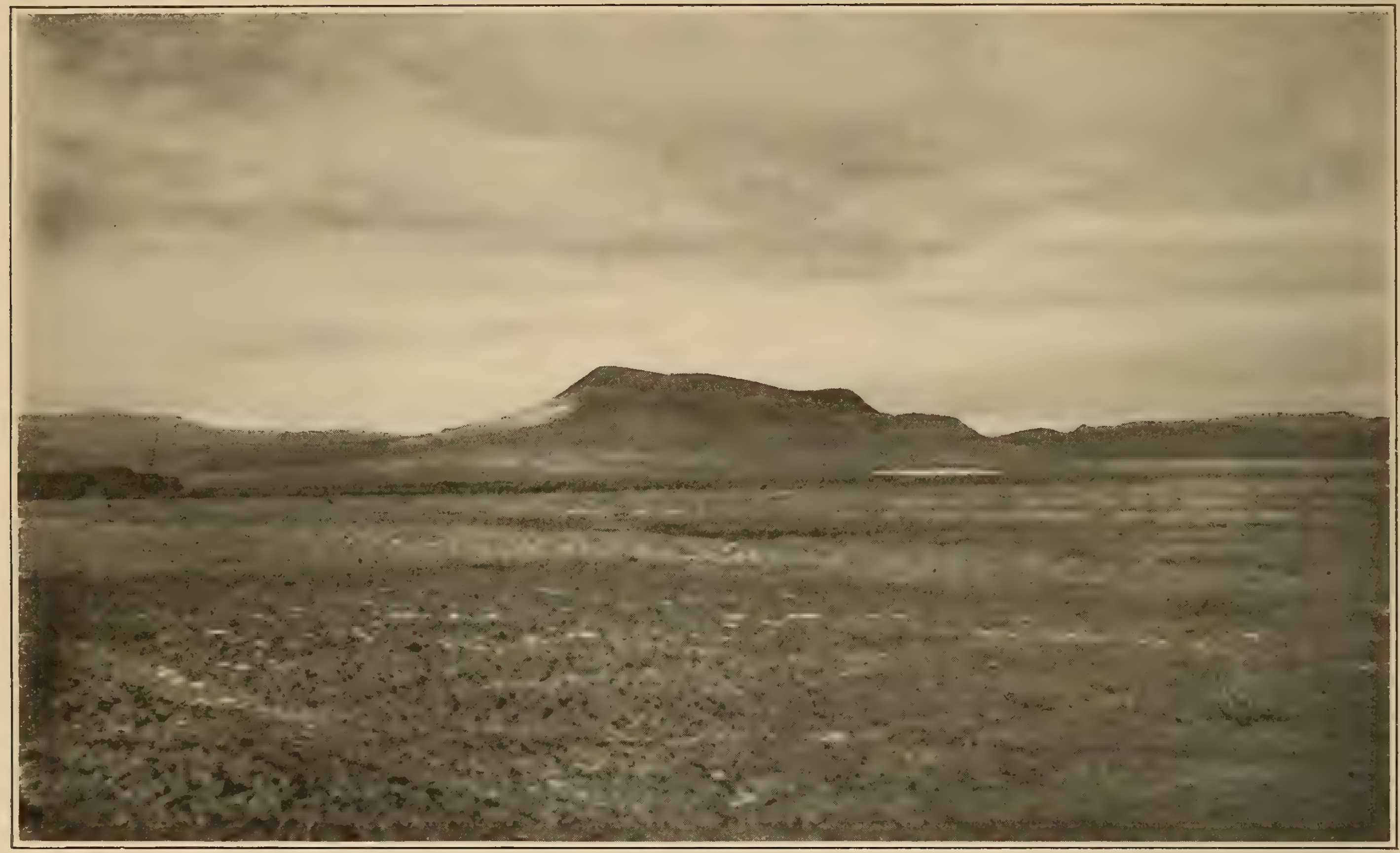

Figure 1.—General View of Lone Mountain

Lone mountain is contoured by Lahontan shore terraces. Trinity mountains in distance

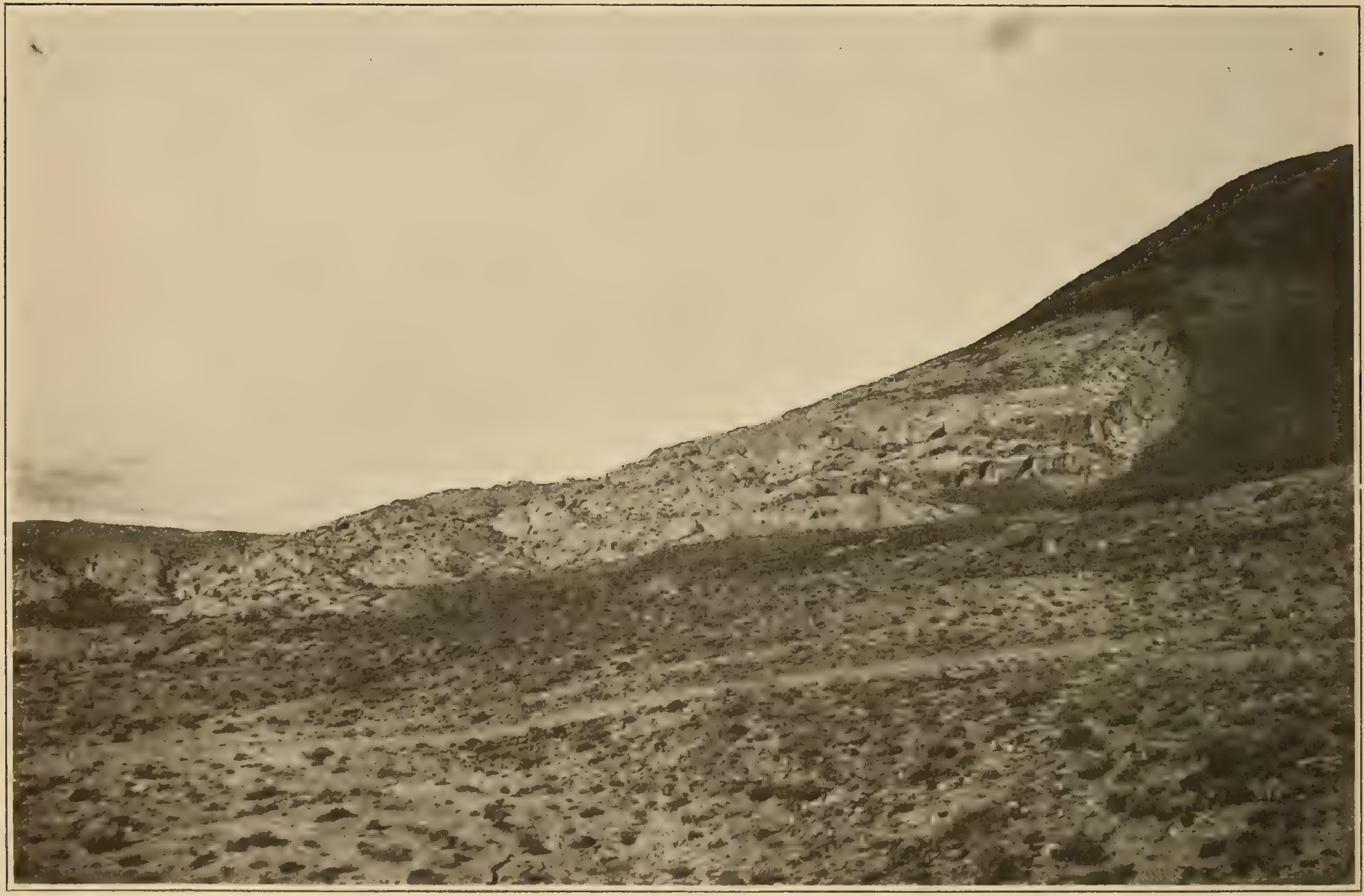

Figure 2.—South End of Lone Mountain

Showing granite, made cavernous by weathering and shore action, overlain by tuff and capped with rhyolite lava

VIEWS OF LONE MOUNTAIN

subordinate ridge, and the basalt capping on the low divide all indicate that since the period of basalt eruption erosion has been comparatively slight, both on the mountain tops and in the intermontane valley. The first decipherable event after the basalt extrusion and its dislocation is the formation of the alluvial cones, followed by lake Lahontan. Some of the lower shorelines have been cut in the valley basalt.

Conclusions.—From the above discussion we must conclude that the history of the Table Mountain range and that of the valley range of hills have been very similar to the history of the Humboldt mountains. In fact, the same succession of events has been made out for each of these now elevated areas. The only noteworthy new feature is that presented by Table mountain of a crust block elevated along fault planes on both sides to form a mountain range with but very slight tilting.

THE TRINITY MOUNTAINS

Extent of investigation.—The Trinity mountains are the next west of the Humboldt. No general study was made of them, but the detailed section was run across into their lower slopes, and their east flanks were studied for some miles north and south. A number of similarities to the conditions in the other ranges were found.

The bedrock complex.—Where examined along the east flank the bedrock complex consists of granite with thick layers of hornfels, into which it has, of course, been intruded. The metamorphism has been so complete that the relationship of this hornfels to the rocks of the other ranges can not be determined.

The superjacent volcanics.—The volcanic rocks are displayed in a complete series identical with that on the east side of the Humboldt Lake range:

Basalt (summit of series, always at surface).
Tuff.
Rhyolite lava.
Tuff (base of series).

The tuffs are sometimes very pumiceous and are generally distinctly stratified. Layers of sand up to 6 inches in thickness were found at one locality. The thickness of the basal tuff series varies from a few feet to several hundred. The upper tuffs are generally comparatively thin and, where not capped by basalt, are removed from the rhyolite surface. Where carefully observed at two different localities, the basal tuffs appeared to have been tilted before the outpouring of the rhyolite.

There are indications that the rhyolite was furrowed by corrasion before the outpouring of the basalt, although no distinct angular unconformity between them has been observed.

The summits of the range to the west of Lovelock are covered with basalt, which slopes off in long, regular sheets.

In general.—The Trinity mountains have not the homogeneity of the other ranges discussed, and the movements that have affected them in both their pre- and post-Tertiary-volcanic times seem to have been more complex than for the other ranges. No attempt was made to decipher the details of their history.

Lone Mountain hills.—About 2 miles east of the base of the Trinity range lies a short range of hills which in its relationships to the Trinity mountains is similar to the valley hills before Table mountain. The detailed section passes over the highest one, which is called Lone mountain. This hill rises about 650 feet above the valley floor and is capped by rhyolite. The rhyolite is underlain by tuff and this again by granite and hornfels. The tuff and lava dip to the northeast and go down below the valley floor, the even surface being broken only by the Lahontan shore lines. Plate 19, figure 1, shows Lone mountain in the center, with its associated hills passing off to the left. The distant high skylines at right and left show the sloping basalt caps of the Trinity mountains.

The granite is exposed at the left (south) end, rounded and hollowed out by the action of the old lake's waves. This is much better seen in plate 19, figure 2, the south end of Lone mountain. The tuff is rather hidden by the talus. The northeastward slope of the rhyolite and the manner in which it has been cut into by the breakers is well shown in plate 20, figures 1 and 2. To the northeast of this last view the rhyolite dips under the valley. A striking feature of Lone mountain is the plane surface of the granite on which the tuffs were deposited. This is also very evident in the Trinity Mountains foothills.

No break occurs in the valley from Lone mountain to the basalt flats at the base of the Humboldt mountains, 8 or 9 miles away.

On the Fortieth Parallel Survey map a patch of basalt is represented on the west side of Lone mountain in such a position that it must either have been deposited before the rhyolite or since the period of deformation. A careful search was made for this basalt, but none could be found. A black, hard, compact rock does occur there, but it is a highly metamorphosed rock into which the granite is intrusive. It will be described later.

DISCUSSION OF SPECIAL FEATURES OF DETAILED SECTION

METHOD OF PREPARING THE SECTION

Sections across the Basin ranges, which have hitherto been published in connection with discussions of the Basin Range type of structure, are sketched to represent ideal conditions and are generally given with

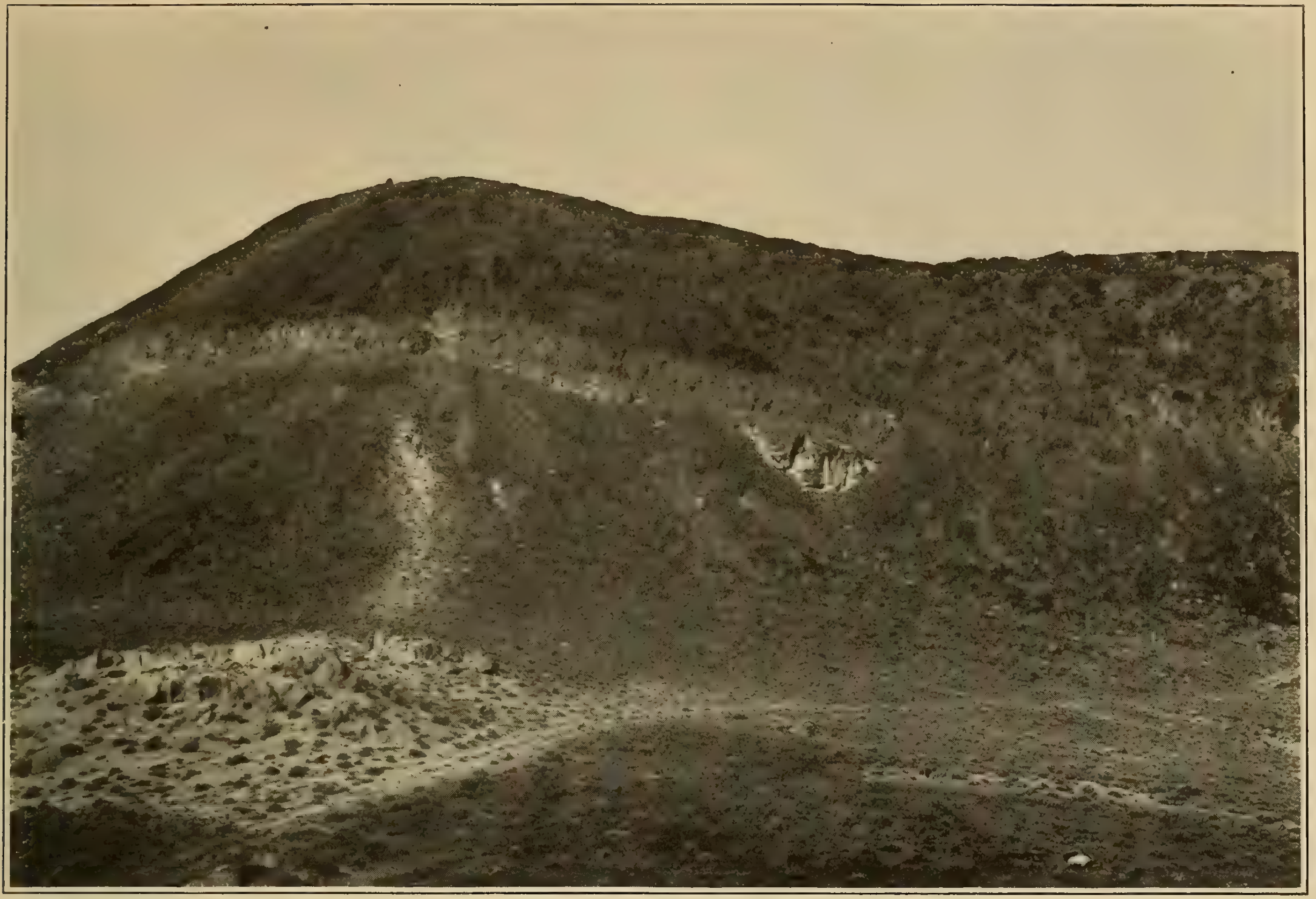

Figure 1.—Central Part of Lone Mountain, looking west

View shows rhyolite (dark) overlying tuff (light) and granite (foreground). Rhyolite and tuff dip northeast. Above granite is Lahontan terrace. Fault traverses mountain as shown by dislocation of rhyolite at right

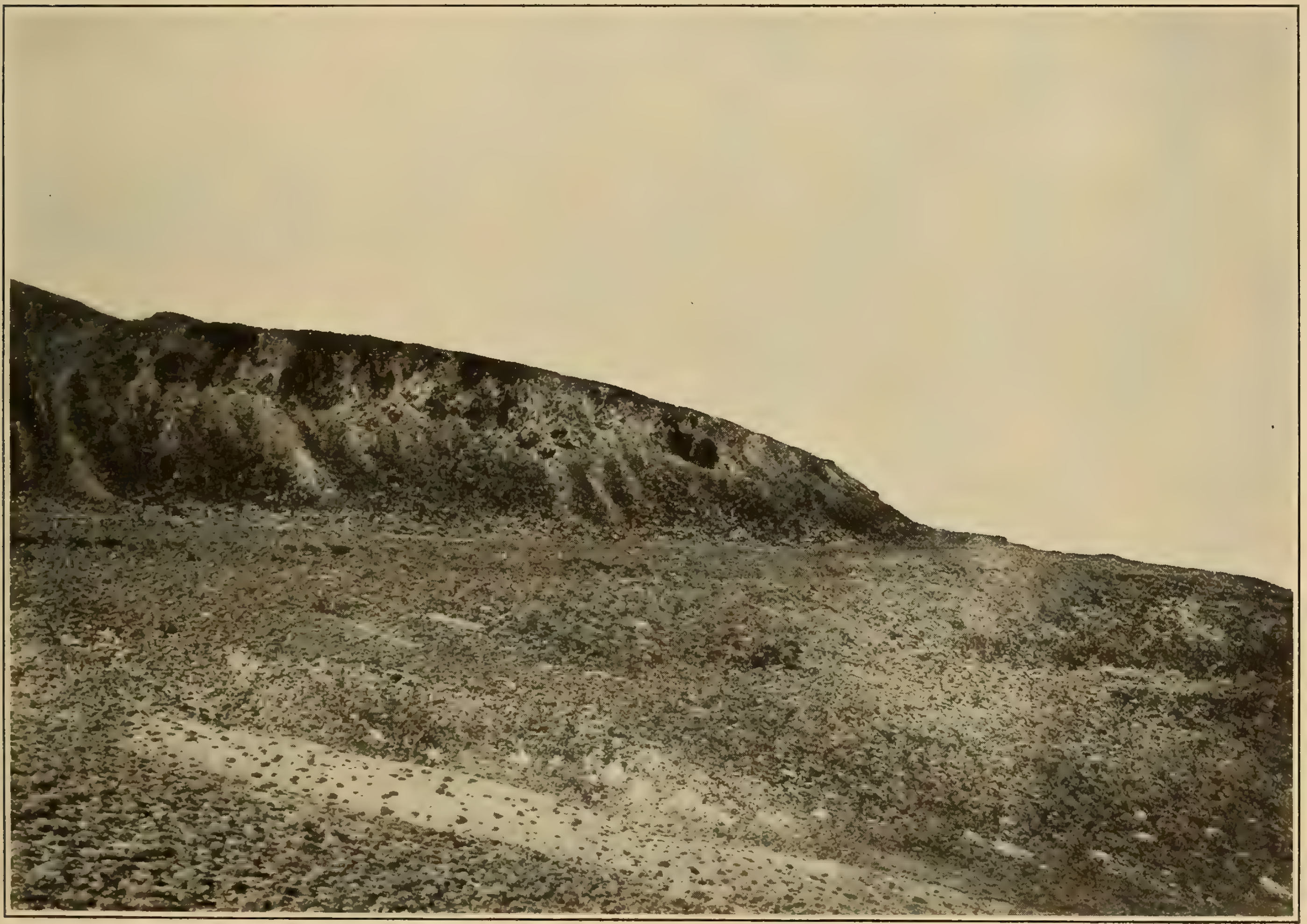

Figure 2.—North End of Lone Mountain, looking west

Rhyolite cap and Lahontan terrace and cliff distinctly shown

VIEWS OF LONE MOUNTAIN

greatly exaggerated vertical scale.* It has seemed desirable therefore to present a carefully surveyed profile, on which are plotted the observed geological features, so that the relative heights of mountains and valleys, the angles of slopes, the details of sculpture, etcetera, may be seen in true relationship and on natural scale. Pursuant of this purpose, the valleys have been surveyed and included, for no true idea of the Basin region can be obtained without an understanding of the broad and floor-like valleys which, quantitatively, are often more important than the intervening ranges. A brief description of the special features of the section, not otherwise noted, will here be given, passing from west to east. The position of the section, which follows a line broken at several points so as to strike the exposed lowland basalt areas, is shown in the map, plate 21.

THE WEST END

The section begins in the foothills of the Trinity mountains, 1,400 feet above the town of Lovelock, in the middle of Humboldt valley. From this point west the slope gradually rises, bearing the complete volcanic series toward the summit. The hill from which the section starts is capped by rhyolite lava, but just north of it the basalt is found occupying the top of the series—the surface layer. The rhyolite is somewhat over 200 feet thick, and is underlain by about 500 feet of tuff, which appears to dip southeast at a moderate angle. At the base of the slope is a stream channel. Coming from the south, it joins one from the west a few hundred yards beyond the section. The section, then, to the margin of the range follows the side of a stream valley from which the rhyolite and tuff have been largely removed. Wherever removed to its base, the tuff is seen to have been deposited on a granite or hornfels floor. The hornfels is dark colored and compact and is broken through by coarse tourmaline-bearing pegmatite dikes.

Between the margin of the range and Lone mountain extends a 2-mile gentle slope, covered along its upper part with alluvium. In some of the rain gullies near Lone mountain the friable, fine grained, deposit looks very much like Lahontan sediment, though no deep cut exposes the beds. That the lake occupied this stretch there is abundant evidence in shorelines and tufa deposits, and the long line of low tufa domes extending north parallel to the margin of the range is proof that only a very slight amount of deposition or erosion has taken place since the disappearance of the lake.

LONE MOUNTAIN

The structure of Lone mountain has already been described and illustrated.* Owing to its direction, the section does not show the tilting of the volcanics, which is mainly to the north. The eastward component of the dip is masked by the deep wave-cut terrace and bold sea cliff, 300 feet high, shown in plate 20.

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*Gilbert's original sections in Wheeler survey are, however, drawn to true scale.

On the south and west side occur exposures of hornfels imbedded in the granite and broken through by many small aplite dikes. This hornfels is black on a fresh fracture, with a slightly pink tinge. It is very tough, fine, even grained, and rings like an anvil under the hammer. On exposure to weathering a thin dark brown film forms on the surface, which, with its other characters, makes it resemble basalt very closely. On account of its peculiar nature and because it has been mistaken for basalt, and as it is a type of rock abundantly represented along the eastern edge of Trinity mountains, a description of its microscopical characters is here given.

The Lone Mountain hornfels under the microscope shows a very fine and, in general, even grained holocrystalline structure. The chief mineral constituent is quartz. Careful search failed to give any definite test for orthoclase, and only a single minute grain of plagioclase was seen. The next most abundant mineral is a reddish brown biotite. It has the color of a red garnet in thin-section, and never shows the dark brown or opaque basal sections so common in the biotites of the granites. Its pleochroism is very distinct, from yellow to brown, and in relation to its other properties is, as usual, diagnostically important. This biotite occurs in irregularly shaped anhedrons or in short rod-like sections parallel to the cleavage. It makes up one-third or more of the rock. Grains of magnetite are sparsely scattered through the mass, and muscovite is present in occasional colorless flakes. A few small, highly refractive grains may be a colorless garnet. The quartz shows frequently a peculiar structure. It forms fair-sized aggregates of grains, which extinguish almost exactly simultaneously and occasionally appear to be really a single individual. In the center of such aggregate or large crystal occur biotite and other minerals, while the outer zone is perfectly clear and of quartz only. These outer zones may be wreath-shaped, V-shaped, etcetera. In the rest of the rock the quartz occurs as irregularly shaped grains mixed quite evenly with the biotite.

THE HUMBOLDT VALLEY

From the foot of Lone mountain the Humboldt valley stretches out as an almost perfectly flat floor, except where cut by river or ditch trenches for somewhat over 4 miles. Then the sand dunes begin and the valley rises slowly (100 feet in 2 miles) to the base of the alluvial slope from the Humboldt mountains. At present the central part of this valley is covered with the horizontally laid and exceedingly fine grained alluvial deposits of Humboldt river, which, after its journey of perhaps 340 miles, is dissipated and disappears entirely a few miles south of the line where the section crosses the valley. Under this alluvium lie the Lahontan beds, of unknown depth, but probably a few hundred feet. They are not exposed by a cut where crossed by the section, but their presence is inferred from the relation of the valley floor to bordering shore features. Some miles up the river they are beautifully displayed in the river trench, which is a hundred feet or more deep in places. They are chiefly well stratified, but unconsolidated light colored sands and clays.

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*See page 328.

The alluvial cone on the east side of the valley has already been described.

THE HUMBOLDT LAKE MOUNTAINS

The depth of the basalt on the hill at the base of the mountains and what rock, if any, separates it from the bedrock are not determinable. It has a dip to the west, but only one-half that of the general range slope. An erosion trench from one to over two hundred feet below the summit of the basalt hill separates it from the range slope. The mountain side of this depression is everywhere bedrock. The area of basalt a mile or two north of this is broader and practically horizontal except at its southeast end, where it dips south, as shown in plate 17, figure 1. This northern basalt is furrowed by Lahontan shorelines carrying rolled basalt pebbles, and it also carries deposits of lake tufa.

The section starts up the mountains on the side of a canyon, and the swinging of this canyon and the occurrence of diagonally feeding streams are the chief causes of the irregularity of the slope.

At about a mile from the west base the main drainage channel turns almost at right angle and heads north. If we follow the line of the trunk stream eastward a divide of vertical slates 250 feet wide at its base and 60 or 70 feet high must be crossed, and then a canyon continues the line up to the summit. The drainage down this upper canyon turns at the low divide, runs south for a short distance, and then turns west down the next canyon of the lower slope. These peculiar north-south stretches trace closely the locus of a fault along which the east side has risen and the west side dropped. This is described because it is a type of a number of cases observed in these mountains where stream lines follow fault planes and where fault planes explain what would otherwise appear anomalous drainage configurations.

We may call those streams which follow a fault plane consequent, when the stream was forced into that path by the actual uplifting of one side with respect to the other, with concurrent deformation of the topography, while streams that have gradually worked into such a path on account of the disparity in hardness between the two walls or because of the weakness of the crushed zone, just as streams gradually establish flow lines along soft strata, may be called subsequent. This distinction can not, however, always be made in practice.

In this sense the fault gulches just described are believed to be consequent, for (1) the rest of the drainage above and below them is of an unadjusted juvenile character, and an adjusted development in the midst of it and so sharply separated would hardly be expected; (2) the rocks of the two walls are the same lithologically, the fault being determined by discordance of attitude, and (3) the fault is parallel to the system of normal faults which on the east slope have produced many consequent stream valleys.

The fault valleys on the east slope are quite abundant. As described above,* the faults can be determined easily stratigraphically on account of the simplicity of the rock series. Several are shown in the section, and also in plates 17 and 18. The chief interest in these faults is that they show that the volcanic series has been in many places dislocated by normal faults; that the mountain block is broken into secondary blocks by minor faults, which state of affairs by analogy we expect in the valley blocks; and that extension, not compression, has been the dominant physical condition in the deformation of the volcanic series. The fault valleys in the volcanic series also show us that consequent drainage lines may have properties commonly supposed to be characteristic of subsequent stream channels in particular, extension along the strike and in soft strata, and extension parallel to the axis of uplift. Such characters, therefore, are not sufficient tests of subsequent streams unless recent faults have been proved not to exist.

The summit basalt breaks off in a precipitous cliff facing westward, down which the slope descends by a series of slips with planes close together, thus covering the cliff face with basalt (not simply talus) and absolutely obscuring the underlying tuff. This obscuration of the tuff has been noted at many places, and its presence has sometimes been difficult or even impossible to ascertain except by following the exposure a mile or more.

A mass of diorite is exposed near the summit and continues down the east side of the range. Its distribution is unsymmetrical with respect to the range crest, as it is mainly on the east side. The eastward dip of the rocks not far west of this diorite (60 to 65 degrees), which would be flatter if the mountains were so depressed that the volcanics became almost horizontal again, is perhaps an indication of the original laccolitic character of the intrusive. This point was, however, not further investigated.

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* See pages 305 and 314.

The alluvial slope on the east side of the mountains does not represent a complete cone, for the section strikes the main cone quite a distance from its apex, which is south of the section line.

THE CARSON DESERT

There are 5 miles of almost perfectly flat valley between the bottom of the cone and the low divide between the Carson desert and Buena Vista valley. There is no stream in this valley, and during most of the year it is perfectly dry. Good shorelines are cut into the mountain flanks. Most remarkable of all, a series of great semicircular lines may be seen crossing the valley bottom, each with its concavity toward the distant Carson sink. These are the traces of a receding shallow lake. It would seem as if but a few months had elapsed since the waters were on the valley bottom. One would think that a single dust storm such as spreads over the Humboldt valley would obliterate all these lines, and that a single year of winds would cover up the bunches of tufa; but there is practically no sand or dust drifting in this valley. Its bottom is like a well kept floor, except where the occasional wagon wheel cuts up the dust on the road. The valley is underlain by Lahontan sediments to an unknown thickness.

The lowest part of this valley where crossed by the section is at the same altitude as the lowest part of the Humboldt valley.

THE LOW DIVIDE

The nature of the peculiar low divide between the Carson desert and Buena Vista valley has already been discussed.* Where crossed by the section it is of diorite, but a horizontal sheet of basalt caps it a short distance to the north. The higher lake waters covered it many feet, but when lower the waves swept over it, removing some of the basalt, and when still lower notched the sides.

MUD HOLE FLAT

Between the divide and Chocolate butte is a broad stretch of lake bottom in the middle of which is a depression that was an old strait of the lake when the latter was at a very low level. This whole area forms a basin separated from the Carson desert by the divide, and from Buena

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*See page 324.

Vista valley by a low alluvium covered roll. Water gathers in winter in the playa called the Mud hole, where animals find drinking water until summer.

CHOCOLATE BUTTE

This is the most northern of a range of hills running along in front of the Table Mountain range for some miles and separated from it by a flat valley where crossed by the section. The interesting features are: the occurrence of the volcanic series, basalt, tuff, rhyolite, resting on bedrock, which is exposed a little south of where the section crosses; the eastward tilt of the volcanics, which pass underneath the valley, with a structure closely comparable to the structure of the Humboldt Lake mountains, and the normal faulting of the volcanics on the east side, three distinct planes being determined in a space of 1,000 feet. The strict analogy of the whole to the Humboldt Mountains uplift is very instructive.

TABLE MOUNTAIN

After leaving the shorelines on the east side of Chocolate butte, and passing over 1¾ miles of valley bottom, the section mounts a long alluvial cone.* This is unbroken by shore features, and gives a very regular slope.

The irregularity of the bedrock complex on the mountain slope is very evident. Just south of the section line diorite intrusions are encountered. A layer of gypsum, whose white outcrop is visible across the broad valley, occurs about two-thirds of the way up the slope. A similar deposit occurs a mile or so north of the section, on the west flank of the Humboldt mountains. This emphasizes the similarity of conditions of deposition of the Triassic group in both ranges.

The faulting of the basalt on the west edge of the table produces a striking appearance. The mountain rises by a succession of steps, each rise being a fault scarp, each tread a flat basalt covered shelf.

OUTLINE OF THE GEOLOGICAL HISTORY OF THE DISTRICT

TRIASSIC TIME

The oldest events of which definite knowledge has been obtained are those connected with the deposition of the Triassic strata. The nature of the floor on which these rocks were laid down has not been determined and is not evident from a study of the area examined. The abundance of Ceratites, Ammonites, Pseudomonotis, and other mollusks, and of crinoids, and the occurrence of Ichthyopterygian vertebrates † give an idea of the character of marine conditions under which they existed. The rocks themselves indicate varying conditions, as might be expected during so long a period of time, but there is a striking predominance of those types which denote shallow water or terrigenous origin. Quartzites, coarse oolitic limestones, pebble-bearing and originally brecciated limestones and gypsum indicate the former; quartzites, slates, and argillaceous limestones, the latter. Pure limestones are rare and are not thick; conglomerates were not seen. In other words, deep-sea forms at one extreme and shore products at the other are not in evidence.

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* For certain dimensions, see p. 302.

† Merriam: Bull. Dept. Geol., University of California, vol. iii, no. 4.

The sea in which these rocks were deposited probably opened to the Pacific ocean on the west, as rocks of the same horizon and of very similar fossil contents have been found in northern California and at some intermediate points, while over eastern Nevada and western Utah no post-Paleozoic marine deposits are known. The shore of the Triassic continental mass may be taken as about 35 or 40 miles east of Table mountain, so the conditions were evidently those of slowly deepening sea, the bottom of which, at least from about 35 to 60 miles * from shore, was at times so near the surface as to permit of the formation of coarse oolitic limestone and limestone breccia, and at times inclosed to such an extent as to allow gypsum beds to be deposited.

JURASSIC TIME

Some deformation and erosion probably took place at the end of the Triassic, but of comparatively limited magnitude, for the Jurassic is disturbed and folded and altered to about the same extent that the Triassic is. The Jurassic continued the marine conditions of the Triassic, showing a preponderance of terrigenous shales, with some limestones. Ammonites, belemnites, etcetera, are common life forms. The conditions were chiefly those of a sea (more open, perhaps, than the Triassic sea) receiving muddy sediment. This is characteristic of the same period in the Sierra Nevada.†

POST-JURASSIC UPHEAVAL ‡

At the close of the Jurassic period of sedimentation, this region was subjected to extensive folding and was lifted above the level of the sea. No trace of marine deposition from that time to the present has been found anywhere in the vicinity. It is probable that the great amount of deformation by folding produced at that time resulted in the formation of mountains of considerable magnitude. We may conclude this both from the extent of the folding, and especially from the magnitude of the resulting denudation, which has stripped large areas of granite of their thick covering of Mesozoic rocks. If we divide the circle of azimuths into four parts by northeast-southwest and northwest-southeast diameters, we may say that the axes of uplift—the anticlinal axes—as far as observed, lie almost entirely in the north and south quadrants, and particularly cluster near the north-south line. Axes lying in the east-west quadrants are very rare and are neither long nor important. As a general rule, it may be stated that the axes of folding commonly lie more east of north and west of south than the ridge lines of the present ranges.

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* These are the approximate straight-line distances of the Table Mountain and Humboldt range gypsum deposits respectively from the shoreline, as determined by the limit of the Mesozoic formations. They represent therefore minimum estimates.

† The Mariposa slates of the Gold Belt.

‡ The youngest Mesozoic fossils found by Professor Smith in this region are Liassic, and it might be more accurately termed the post-Liassic upheaval. The above term is retained, however, for uniformity in nomenclature, and because it is quite probable the movements were contemporaneous with those in the Sierra Nevada.

It was probably at the time of the post-Jurassic upheaval that the greater part of the granite was intruded. As far as the direct evidence of intrusion at the localities studied goes, this might have taken place at the close of the Triassic, as the only rock of definitely determinable age with which the granite has been found in intrusive contact is Triassic; but the comparatively small disturbances at that time and the great disturbances at the end of the Jurassic, combined with the fact that farther west the intrusion of great masses of granite in post-Jurassic and pre-Chico (Upper Cretaceous) time* is well established, makes a strong case for the close of the Jurassic as the time of the intrusion of the granites of the Humboldt and the East ranges.

Nothing has been said about volcanic activity during the early Mesozoic, or about the intrusion of the diorites. The existence of both has been determined, but the character and extent of the Triassic eruptives and the age of the diorites were not investigated.

THE GREAT EROSION INTERVAL

Following the post-Jurassic disturbances, a long period of subaerial erosion was inaugurated. There were apparently no indications of a "great basin" at that time, and the drainage probably passed freely to the sea, for no deposits corresponding to Cretaceous time are found anywhere in the Basin region today, while exceedingly thick deposits occur along the coast and along that region east of the Great basin that was covered by the epicontinental Cretaceous sea. These deposits show by their character, thickness, and remarkable changes in their included organic forms that the Cretaceous was a very long period.

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* See citations, p. 319.

How long this period of elevation and erosion continued has not been definitely determined, because the time of the next succeeding event has not been satisfactorily established. That the processes of elevation discontinued very long before the erosion period closed is evident from the fact that a topography of very low relief was produced. In the Sierra Nevada, it may be noted, the post-Jurassic upheaval was practically brought to a close before the beginning of the deposition of the Chico beds * (Upper Cretaceous).

The first disturbance during this erosion period, of which a record has been found, is that warping of the topography which produced the freshwater lakes. The oldest lake deposits thus far recognized in this district are the Truckee beds. These were considered by the geologists of the Fortieth Parallel Survey to be of Miocene age, but the evidence is of an unsatisfactory character—chiefly some freshwater mollusks of doubtful horizon,† and general deductions from the amount of deformamation. The type locality, Kawsoh mountain, lies just at the south end of the Humboldt valley. Observations made near Reno, Nevada, however, on what are presumably Truckee beds, indicate that these deposits are probably Pliocene.

We may say, then, that the period of erosion extended without any other notable contemporaneous event through the Cretaceous, the Eocene, and part of the later Tertiary time. Then occurred the warping which produced the lake or lakes in which the Truckee beds were deposited. The country remained of rather low relief, and during some stages diatomaceous ooze was abundantly deposited over large areas.

VOLCANIC ACTIVITY

It was during this period of crustal warping, perhaps near its close, that volcanic activity broke out in the form of explosive eruptions. Judging from the relationships shown in the Trinity foothills, deformation took place after this tuff-forming period, and was followed by outpourings of rhyolite lava. Then, again, the country was covered with the products of a series of explosive eruptions.‡

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* Turner: U. S. Geol. Survey, Seventeenth Annual Report, p. 547.

† Report of the Fortieth Parallel Survey, vol. ii, p. 767. The fossils there given are *Carnifex* (*vortifex*) *binneyi*, *C.* (*v.*) *Troyoni*, *Ancylus undulatus*, *Melania sculptilis*, *M. subsculptilis*, *Sphœrum ? rugosum*, and *S. idahoense*. The report says, "They are all of decidedly freshwater types, and have been referred by Professor Meek to the Miocene or later formations, but on structural grounds, . . . they are regarded with but little hesitation as belonging to the Miocene age." A *Rhinoceros* tooth is also reported, but of undetermined species.

‡ The relationship of the Truckee beds and the rhyolites and tuffs is not shown at any of the localities studied during this investigation, but according to the Fortieth Parallel Survey, vol. i, p. 644, the rhyolite distinctly overlies the lake beds, and Mr J. T. Reid, of Lovelock, reports the same sequence from the Trinity mountains. It is possible that the (sometimes tilted) tuffs under the rhyolites were deposited conformably on the Truckee beds, and may be considered part of that formation.

After a brief quiet period a flow of basalt flooded many square miles of the district investigated, some small areas receiving several successive coats, and then all volcanic activity ceased.

OROGENIC DISTURBANCES

Whether the Great Basin region was being elevated as a whole or not during the Tertiary period of volcanic activity is something which the study of this district did not elucidate, but it is reasonably certain that up to and including the time of the basalt outpouring but slight differential elevation within the limits of the district studied could have taken place.

But after the outpouring of the basalt the region was broken up along great fault lines, and a period of active differential elevation was inaugurated. The major fault planes for which evidence has been given lie along the west side of the Humboldt Lake range, along the west side of the Star Peak range and running through and determining the transverse valley between these ranges, and along both east and west sides of the East range. The East range was elevated as an inverted wedge, practically without tilting. The Star Peak and Humboldt Lake ranges were tilted to the east, the exposed fault scarp being on the west side only.

During this differential elevation, by which the present mountain ranges and the broad valleys between the ranges were formed, the relatively rising masses and the relatively sinking masses acted on the whole as great blocks, rising and sinking as units; but they were not absolutely rigid units, for we have evidence of internal deformations of two kinds—faulting and warping.

Both mountain blocks and valley blocks are broken along lines of minor faulting into a number of secondary blocks sufficiently well shown in the ideal section, figure 3, not to require further description.

Besides this, we note that the Humboldt Lake range, with its curved fault trace concave to the west, rises from the south out of the plains and gradually grows more elevated, then finally sinks toward the north into the plains again. The fault-throw is greatest in the north central portions and grows less as one goes north or south. In other words, the block has a curvature from north to south, like the axis of an anticlinal fold, pitching north to the north, and south to the south. Faults in general are almost always of this character, each showing a maximum throw, which decreases to zero toward its extremities.

During the period of differential elevation or the period of volcanic activity, perhaps both, the Great Basin region was elevated as a whole from a low altitude to such a height that the bottoms of the great valleys in the district studied are now at about 4,000 feet above sealevel. The tops of the lowest depressed portions of the relatively sunken blocks are probably not more than a few hundred feet below this.

The result of these movements was the production of the Great Basin province as an interior basin, the formation of the ranges under discussion, and of the intermontane landlocked valleys.

Following the production of these ranges and valleys, probably also during their production, there was a rather long period of erosion. During this period the alluvial cones were built up almost to their present size. It is known that the larger rivers, such as the Humboldt and Truckee, were flowing at that time, but no deposits corresponding to their corrasive activities have been found. They probably underlie the Lahontan beds in the deeper portions of the basin.

With the advent of more humid conditions the valleys were flooded by lake Lahontan, which, as Russell has shown,* passed through two stages of high water, separated by an interlake period of desiccation. During Lahontan time the lower parts of the valleys were filled with sediment up to several hundred feet,† and the mountain flanks were scored with the shorelines, which still form such striking features of the topography.

It has been shown by Russell that the period of the Quaternary lakes of the Western basin corresponds closely to the period of glaciation in the Sierra Nevada.‡ The pre-Lahontan uplift and erosion correspond, then, to the Sierran period, and we may consider that the orogenic disturbances described mark the opening of the Quaternary era for the Humboldt region.

RECENT

Soon after the close of the western Glacial period arid conditions again set in and caused the gradual desiccation of the lakes. Lake Lahontan slowly passed away, and left, among other Recent remnants, Humboldt lake, just west of the southern part of the Humboldt Lake range; but even this has disappeared within the last few years—since the introduction of irrigation along the river—and the Humboldt river is entirely dissipated before reaching the old "sink."

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*U. S. Geol. Survey, Monograph xi.

†It appears that a number of geologists are unaware that the "Humboldt Pliocene" deposits of "Shoshone" lake described by King for the Humboldt and several other western Nevada valleys, and the Lahontan Quaternary deposits of Russell, are *identical.* They are occasionally referred to as two distinct formations deposited in two different epochs. They are thus described in duplicate in the paper, "Origin and structure of the basin ranges," already cited. The Quaternary age of these beds seems to have been well established.

‡U. S. Geol. Survey, Monograph xi, and also U. S. Geol. Survey, Eighth Annual Report, pp. 369-370.

Since the Pleistocene there has been little change with the exception of the desiccation. Some erosion has taken place, particularly in the upper parts of the ranges, and the great alluvial cones have been brought to their present condition. Faulting has taken place in very recent time along the old lines, the scarps cutting lake features and cones, but only of moderate magnitude—25 to 50 feet or more.

COMPARISON WITH THE SIERRA NEVADA

Anyone familiar with the geological history of the Sierra Nevada must have been struck by its remarkable similarity to that of the Humboldt mountains and vicinity. A brief chronology of each is given here for comparison. Some events have to be stated in a general way to bring out the analogy.

	SIERRA NEVADA	HUMBOLDT REGION
Triassic	Marine deposits, including limestone. Similar fossils in both regions.	The same.
	? ?	Some volcanic activity.
Interim	Some disturbance before opening of Jurassic.	The same.
Jurassic	Marine deposits, chiefly slates	The same.
	Much volcanic activity	No volcanic products noted.
Interim	Great deformation by folding	The same.
	Granite intrusions	The same (possibly, however, post-Triassic).
Cretaceous	Erosion period	The same.
	Drainage to the sea	The same.
Tertiary	Completion of great erosion cycle with production of low relief—partial peneplanation.	The same.
	Great volcanic activity	The same.
	Lake beds deposited	The same.
	A certain amount of deformation in later Tertiary (Neocene).	The same.
Interim	Upheaval by faulting and tilting begun.	The same.
Pleistocene	(1) Period of erosion, probably with continued uplift.	The same.
	(2) Freshwater lakes at east base (Mono, etcetera).	Lake Lahontan.
	Two periods of flooding, with intermediate desiccation.	The same.
	Glaciation at least partially coincident with lake periods.	Glaciation reported from Star peak, but relationship to lake not determined.
Recent	Extensive desiccation of lake basins. Faulting along old lines.	The same.

DISCUSSION OF CERTAIN FEATURES CONNECTED WITH THE FAULTING

MAGNITUDE

The small amount of erosion which the basalts have suffered indicates that the lowering of the surface of the basalt layer has not been very great since the ranges were first uplifted. The line along which the fault plane intersected the basalt would, of course, be most rapidly attacked, particularly by landsliding and other forms of undermining, and its fragments would then be the easy prey of agencies of erosion and transportation. The top of the Humboldt Lake mountains would be seriously affected by this action. The top of Table mountain, while it may have become narrower from that cause, has hardly become lower. We may use it, therefore, as the upper limit in determining the throw of the fault. The lower limit is harder to determine, for the lowest parts are covered. Along the surveyed section the table is 3,400 feet above the bottom of the valley between Table mountain and Chocolate butte. This is a minimum value. The Lahontan and other lake beds may be 300 or 400 feet or more deep at this point.

The basalt in the crumbling cliff where the section crosses the Humboldt Lake range is 1,500 feet above the patch of basalt at the west base and 2,050 feet above the lowest point of Humboldt valley on the section line.

The Star Peak range is the highest of the three, but is not capped by basalt. The amount of faulting can not be safely estimated from the highest peaks, as they may have been residual hills on the old topography several hundred feet high. The ridge line is, on the average, about 3,900 feet above the west valley.*

The approximate lengths of the ranges measured along the fault margins, which practically means the determinable length of the faults, are: Star peak, 32 miles; Humboldt lake, 42 miles. The length of the East range is not definitely known, but it is probably longer than the other two ranges put together.

THE SECONDARY FAULTING

The breaking up of both the mountain and the valley blocks by minor faulting into secondary blocks has already been described. It appears to be a common condition. Section 3, plate 16, shows the east slope of the Sierra Nevada just northeast of lake Tahoe. This slope represents the eroded scarp of the range. The block is here broken by a fault, with a throw of 2,500 to 3,000 feet. Other examples might be given from the same mountains.

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* Topography of Fortieth Parallel Survey.

These secondary blocks are generally discontinuous longitudinally—that is, they may run for a half mile, a mile, or a number of miles, and there cease. This is most strikingly shown in the subordinate valley ridges, several of which have been described, for they form islands in the midst of the lakebeds and alluvium. The longitudinal irregularity of the valley block in another district is also well shown at the east base of the Sierra Nevada, on the Carson topographic sheet,* where the main intermontane valley is broken by subordinate blocks into a series of subordinate valleys.

It is an interesting fact that the greater number of these secondary fault planes are roughly parallel to the primary fault plane, and the throws are in the same sense. If in the main fault the west side was the downthrow, so is it generally in the subordinate faults. This may be seen in the detailed section and in the section of the Sierra Nevada fault scarp (plate 16). In the Humboldt Lake range, where the primary fault is on the west side, secondary faults on the east side show this same approximate parallelism. The most eastern of these shown on the section is 19,000 feet from the west base basalt, only 3,000 and 4,000 feet from the east base of the range, and has a throw of 300 feet (perpendicular to the layers).

RELATION OF MOUNTAIN TO VALLEY BLOCKS

The most striking feature of the detailed section is the breadth of the valleys compared with the ranges. Quantitatively they are the chief features. The structure of the Humboldt mountains, and others supposed to be like them, has sometimes been represented by a great tilted block that passes down under the valley until it strikes the fault plane along the side of the next range. A study of the detailed section shows that no such conception can be held for the Humboldt Lake range and the valley of the Carson sink where crossed by the section. The basalt and bedrock reach the surface twice on the way over. If the basalt slope of the range were continued only to vertically below the west edge of the divide near the center of the valley, it would sink 7,000 feet below the valley floor—a depth in the upper part of the valley that we can hardly imagine filled by deposition since the faulting took place. We know there are at least three secondary valley blocks from the divide to the East range. Why not several between the divide and the Humboldt Lake range, which do not come to the surface? Whether there is flexure at the east side of the Humboldt mountains, or faulting, is not determinable by observation, but the general nature of the readjustments throughout the region would favor the latter.

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* U. S. Geol. Survey Topographic Atlas, Carson, Nevada, sheet.

Southward from the line of the detailed section the valley of Carson sink widens and the valley ridges disappear, so that, as far as observation goes, the structure might be, as has been elsewhere suggested, the tilted Humboldt Mountain block passing down under the valley deposits until it strikes against the East Range block; but even here it is possible that the valley block does not lie at so great a distance below the alluvial surface, and the amount of post-basaltic erosion, judged from the lava-covered slopes, would fall very far short of filling valleys, which are broader than the ranges, several miles vertically with lake beds and alluvium, as would be required by a strict adherence to a single mountain-valley block hypothesis.

The valley blocks are best thought of as separate and distinct from the mountain blocks, even when the tilted mountain surface dips down underneath the present valley floor. The former have, as a whole, relatively sunk, the latter risen.

RANGE SLOPES AND FAULT PLANES

Notwithstanding the breaking down of the fault scarp, especially where it intersects the original surface as described above, all indications point to a relatively small amount of general erosion since the production of this feature.

If in the detailed section we connect with a straight line the point where the bedrock series is first exposed at the top of the alluvial cone with the west edge of the table of Table mountain, the angle with the horizontal is 11 degrees 21 minutes. The angle similarly obtained for the west slope of Chocolate butte is 12 degrees 31 minutes; for the west slope of the Humboldt Lake range, 7 degrees 47 minutes.

It is a very interesting fact that all of these profiles when smoothed out are concave upward, the angle of slope increasing as the summit is approached. This is quite different from the east side of the Humboldt Lake range, which is irregular and in part convex. The western slopes are, in fact, typical erosion profiles, and have developed on the scarp side better than on the basalt-covered slopes, probably because of the scarp's greater initial slope and less resistant covering.

From the youthful character of the drainage, with no appreciable lateral cutting or undermining along the range base, the apparently slight change in the basalt surface layer by general erosion, and from the nature of the profile, it may be judged that the amount of post-basaltic erosion has been comparatively small. It is probable, considering the comparative softness of the rocks and the erosion profile, that the erosion on the west side has been greater than on the volcanic-covered slopes; but a comparison of the drainage forms on both sides of the range, including the alluvial cones, indicates that the difference can not be very great in the amount of material removed. It is possible, therefore, that the present west slope of the Humboldt Lake range and the corresponding slopes of the other ranges may not differ widely in angle from the dip of the fault planes which gave rise to them. In other words, the fault planes may have been of rather moderate inclinations to the horizontal.

Use of volcanic Rocks in deciphering orogenic Movements

The post-Jurassic volcanic rocks seem to have been the despair of some geologists, and a paper already quoted says:

> "Our knowledge of the ranges of northwestern Nevada is comparatively slight, since in this region the volcanic rocks are so abundant that nearly everywhere they mask the structure * * *."

The fact is, that as the only post-Jurassic rocks of northwestern Nevada are volcanics and lake sediments, and as the lake sediments are only sparsely distributed on the mountains, the structure and attitude of the volcanics are frequently the only available sources of Tertiary and Quaternary orogenic and physiographic history, and at the least they almost always offer suggestions and details which would otherwise escape notice. Besides the cases already described in the various ranges and hills in the Humboldt region, an example may be given from the Sierra Nevada. The east slope of the Sierra Nevada has long been supposed to have been determined by a great fault, but physiographic evidence alone can not always determine whether such a fault be single or multiple. Section 3, plate 16, represents the east slope * of the Sierra from the top of mount Rose, 10,800 feet, to Washoe valley, 5,032 feet above sealevel. The bedrock is granite, above which occurs a series of andesitic breccias capped by solid andesitic lava. The identity of the series on mount Rose and on the low shoulder is easily recognized and the existence of a fault immediately evident. Such a fault is as near an "actually observed fault" as one is likely to encounter. The throw is easily estimated, and is 2,500 to 3,000 feet. Its presence might have been indeterminable or have been a subject for controversy had the volcanics not been present.

The writer desires to urge the value of the volcanics in the study of the post-Jurassic history of Nevada. He considers them the key to the succession of events in many of the western ranges. It is evident, however, that volcanic rocks must be used with the utmost care and reserve, for it is difficult to correlate them if the outpourings have been irregular

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* Based on topography of Carson sheet, U. S. Geol. Survey Topographic Atlas.

and in complicated series. Mere lithological similarity or even identity is not alone a sufficient criterion of contemporaneity of extrusion.

It will have been noticed that all the faults which appear in the sections, photographs, or descriptions as breaking through the volcanics, including the Sierra Nevada fault just described, show simple* fault scarps. In his discussion of the fault hypothesis Spurr† says, "The writer has undertaken to show * * * that the ascertainable faults are very rarely attended by simple fault-scarps," and he gives a number of sections showing faults determined by stratigraphic discordance in the Paleozoic rocks, which show either no fault scarp or an erosion scarp. None of these sections include Tertiary or later rocks. The only sections which he presents showing later rocks are figures 1 and 4, plate 24, and in both of these the deformations are shown to be in ascendency over the erosion, the first illustrating faulting, and the second, folding. From the fact that he would not accept a scarp or any other physiographic indication of faulting, and as most of the ranges studied by him carried very little or no post-Jurassic rocks, it is easy to see how Cenozoic faults would be largely overlooked.

In the same way it is said, "According to the accumulated record of observation, ranges consisting essentially of a single monoclinal ridge are exceedingly rare." By this is meant monoclinal in respect to the bedrock; but if, as in Humboldt Lake mountains, a period of folding and erosion precedes the block faulting, the bedrock could only be expected to show a monoclinal structure under rare circumstances, and changes from monocline to anticline or syncline should be not uncommon in the same range. As regards the Tertiary volcanics, the Humboldt Lake range is a monocline, and so also, we might say, would it have been topographically a monocline, even if there had been no post-Jurassic rocks on its surface.

In the paper referred to, the writer has evidently not distinguished pre-Cretaceous from post-Jurassic and especially late Tertiary faulting, folding, or other earth movements. The great Cretaceous–early Tertiary erosion period has, of course, obliterated all of the ancient topographic features, but great faults and other deformations of later Tertiary or Quaternary time are commonly preserved, with but comparatively slight alteration.

Directions for visiting Geologists

In the belief that many geologists crossing Nevada by the Southern Pacific railroad would be pleased to visit the district above described if they knew how easy it is to see the chief features, the following note is written. It requires but a day (6 or 8 hours) to see the main points. The start should be made from Lovelock by team along the Muttleberry road. As you rise above the valley on the foot of the cone, the mountain and its structure can be distinctly seen. The rather flat-topped, dark cliff seen on approaching the mountains and showing Lahontan shorelines is the edge of the larger area of west base basalt. The road runs southward and leaves this to the left, but there is time to go up a branch road and examine the rock before proceeding. The smaller basalt area is just south of the mouth of Muttleberry canyon, in a small disconnected hill, which in the distance does not appear to be made of basalt. It is best examined by entering the gulch opening on its west side.

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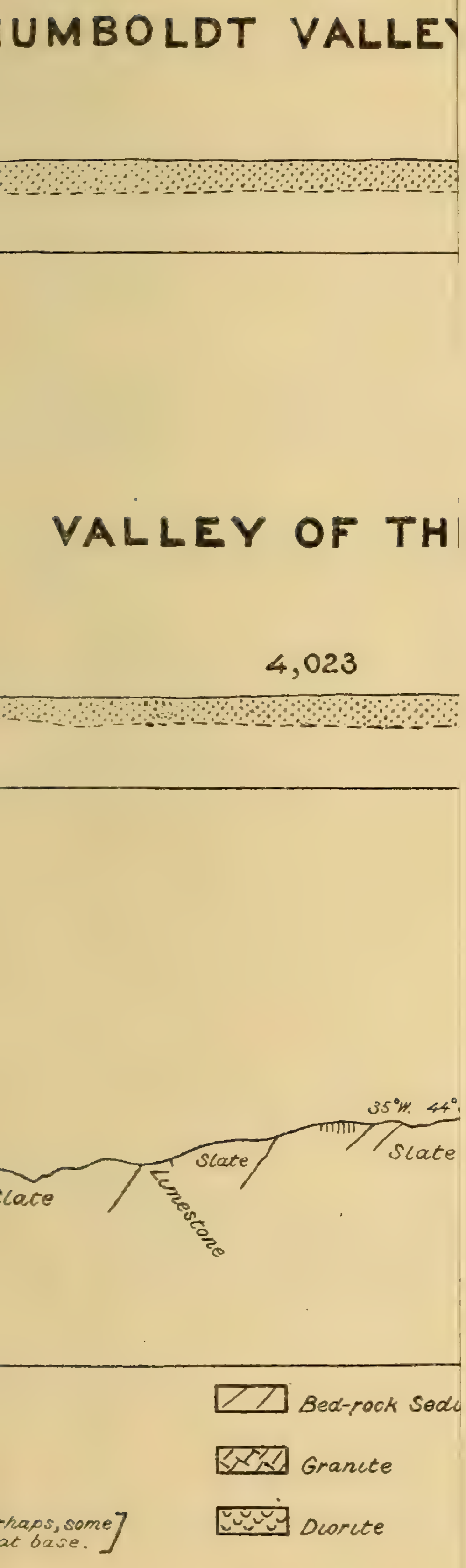
*See note, page 305.

† Bull. Geol. Soc. Am., vol. 12, p. 265.

Up to the summit of the range the structure of the bedrock can be examined. At the summit, looking northeast. the volcanic series, normally faulted and dipping down underneath the valley, can be very well seen. Table mountain lies across the valley to the east, the Star Peak range to the northeast. If a better view is desired, one should not descend the road on the other side, but go southeast along the summit trail until opposite the cone-shaped basalt peak, which should be climbed, and the broad valley of the Carson sink, with the old shorelines, Chocolate butte, etcetera, may be seen as in a great model. Structure as well as topographic form is easily distinguishable, although the state of the atmosphere and position of the sun affect its distinctness to a considerable degree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Lake Shore
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Old Strand at Low water
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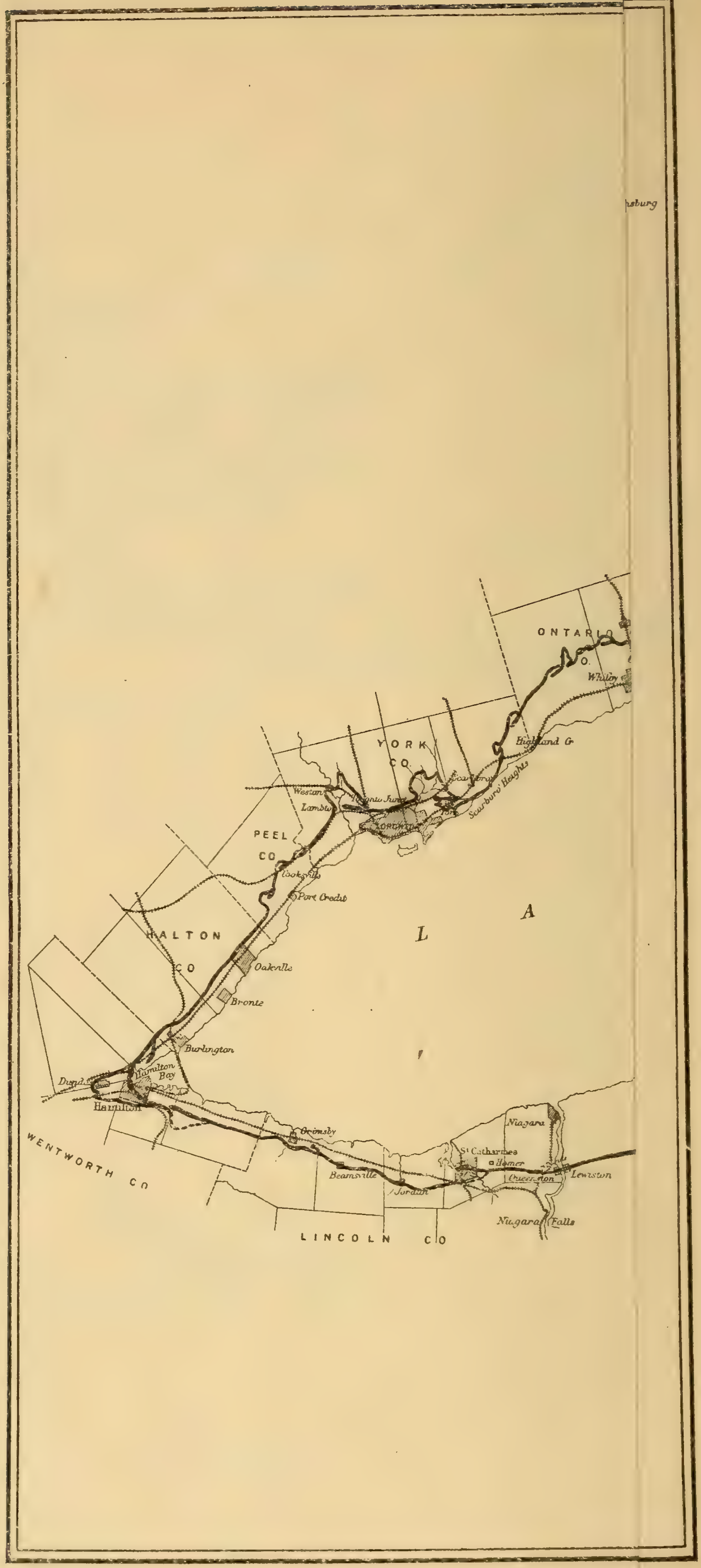
LEGEND
Lahontan and Alluvium
Basalt
Rhyolite and Tuffs
Bed-rock Sediments
Granite
Diorite
Hornfels

Topographically Surveyed, 1903 by G.J.Young.
Geology by G.D Louderback

DETAILED SECTION ACROSS THE HUMBOLDT REGION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Niagara
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IROQUOIS BEACH IN ONTARIO

BY A. P. COLEMAN

(Read before the Society January 1, 1904)

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INTRODUCTION

The signs of wave action in the cutting of cliffs, the piling up of beach sands and gravels, and the formation of bars or spits across the mouth of bays are so well marked on the old Iroquois beach that it was early recognized as a shore formation by farmers and land surveyors, as well as geologists. The first written mention of the beach in Ontario is contained in Thomas Roy's paper on the "Ancient State of the North American Continent," read by Sir Charles Lyell before the Geological Society of London in 1837;* and Lyell was so much interested in the account of the series of terraces which Roy described that on his visit to America he crossed from Niagara to Toronto in 1842 to examine them. Roy noted a number of sand and gravel beaches at various levels above lake Ontario

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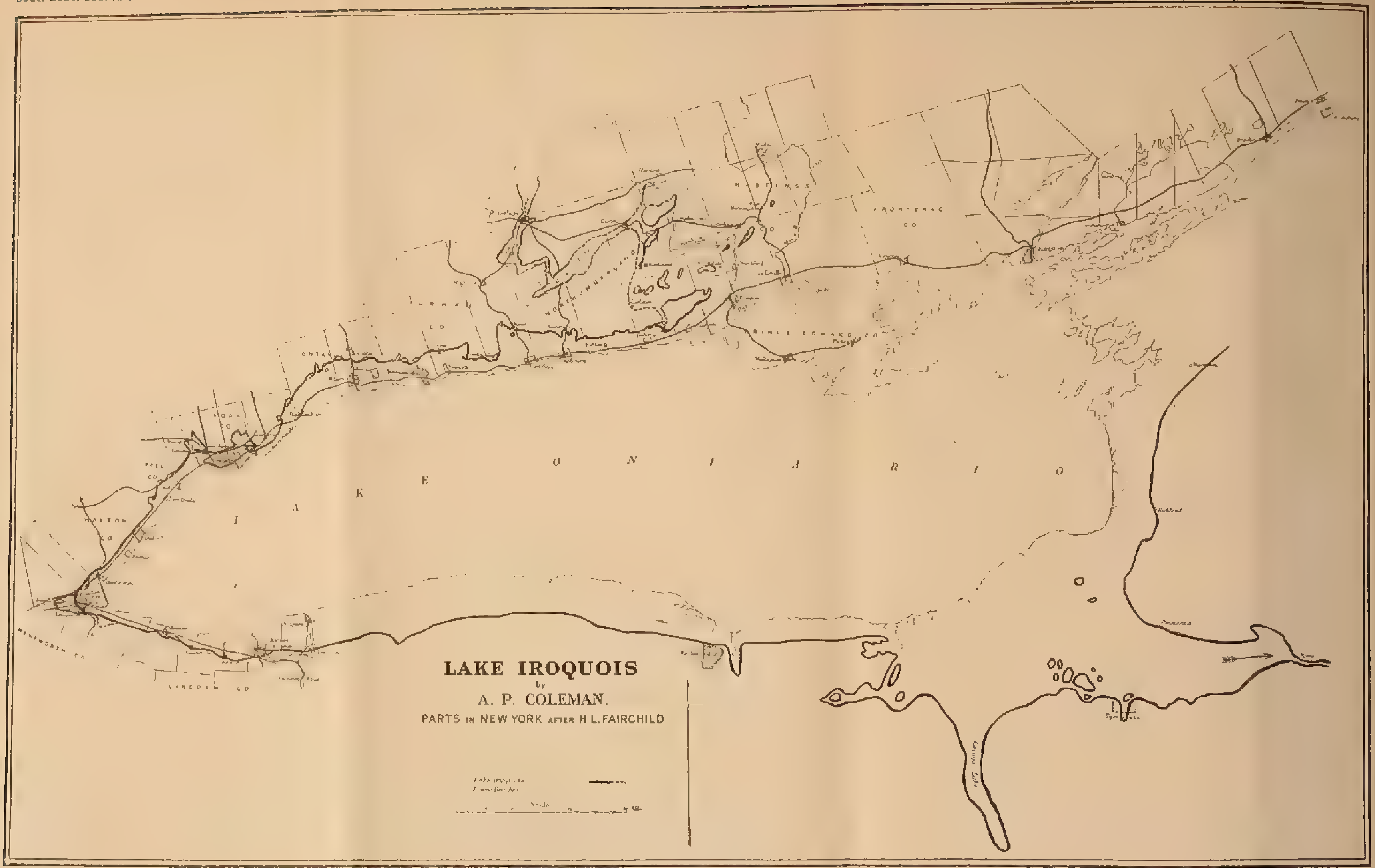
*Proc. Geol. Soc. London, vol. ii, no. 51, pp. 537, 538.


LAKE IROQUOIS
by
A. P. COLEMAN.
PARTS IN NEW YORK AFTER H L. FAIRCHILD
LAKE ONTARIO
HASTINGS
FRONTENAC CO
PRINCE EDWARD CO
NORTHUMBERLAND
DURHAM CO
ONTARIO
YORK
PEEL CO
HALTON CO
WENTWORTH CO
LINCOLN CO
Richland
Cayuga Lake
Scale

MAP OF LAKE IROQUOIS

up to 762 feet, and Lyell agrees with him in regard to some of them, though not certain that all were really beaches. Later students of the region have found only one well marked beach out of the supposed series, the one now called the Iroquois beach. This was Roy's second shoreline, which he places 208 feet above lake Ontario, his measurement being about 30 feet above the real level. Lyell compares the beaches which he saw to the parallel roads of Glen Roy,* but in the backwoods behind the new town of Toronto he had apparently poor opportunities to follow the supposed terraces and discover whether they were really due to wave action.

Both Roy and Lyell had theories to account for the supposed beaches, Roy imagining ranges of mountains to the south and east holding in a great lake until the water slowly cut down its outlet and drained the basin to its present level, while Lyell preferred to suppose that the beaches were marine and formed when the land stood lower; so that the controversy as to the character of the water had already begun.

To give in detail the literature which has grown up about this interesting subject would take too long, and references to it may be found in papers by Doctor Gilbert,† Doctor Spencer,‡ Professor Fairchild,§ and the present writer.|| It may be said in a general way that Doctors Gilbert and Spencer, on the south and north sides of lake Ontario respectively, worked out the elevation of a number of points on the beach and proved conclusively that it is deformed, having been differentially elevated toward the northeast. They published similar sketch maps of the old shore, giving for the first time a clear idea of the area of the ancient body of water, but they differed as to its character, Gilbert considering it to be an ice-dammed lake with a well marked outlet past Rome and through the Mohawk valley into the Hudson, while Spencer thought the beach could be traced from point to point along the Adirondacks to the east beyond the supposed ice dam, and hence must have been formed at sealevel as an extension of the gulf of Saint Lawrence.

In 1890 Professor Fairchild described the different levels into which the beach is split to the north of the Rome outlet, as far as Watertown, New York, and concluded that the warping of the old beach was largely produced since Iroquois times. His report is accompanied by a map of much larger scale than those hitherto published, but, as far as the north shore is concerned, he merely reproduces Spencer's rough sketch, while

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* Lyell: Travels in North America, vol. ii, pp. 103-106.

† Sixth Ann. Rept. Commissioners, State Reservation, Niagara, 1890, p. 67 et seq.

‡ Trans. Roy. Soc. Canada, sec. iv, 1889, pp. 121-134, and Duration of Niagara Falls, p. 44 et seq.

§ Pleistocene Geol. Western New York, Rept. Progress, 1900, p. r 107.

|| The Iroquois Beach, Trans. Canadian Institute, vol. vi, p. 29 et seq.

on the southeast side he omits two large islands shown on Doctor Gilbert's map. My own work of mapping in detail the part of the beach within the province of Ontario was practically completed two years ago, but publication was delayed in the hope that the shore might be traced farther to the northeast than Havelock, the last point near which it had been found with certainty.

Several visits to the region between Campbellford and Havelock, on the north side of Trent river, and also to the hills north of Madoc, which rise high enough to receive the beach and are in part covered with boulder clay suitable for beach cutting, gave negative results, and the conclusion has been reached that the old shore either ends near Havelock or is too poorly marked to be followed beyond that point.

Except where broken by river valleys, the old shore can be followed with scarcely an interruption from New York state round the west end of lake Ontario to Hamilton, and then northeast as far as Trenton, where it bends to the north, forming a great bay with many islands. The extreme northeast point of the shore, so far as known, is on a small island near West Huntingdon, on the Madoc railway, and the most northerly point is just north of Trent river, near Trent bridge.

Over long stretches the beach is occupied by main roads or by railways, and in those parts is easily studied; but toward the northeast, as it rises higher along the flanks of the great range of morainic hills extending toward Trenton, it leaves the better settled parts of the province and must be followed on foot, owing to the often rough and wooded character of the country.

The best maps to be had in Ontario are the old county maps prepared long ago, often before many of the railways and highroads were made; so that in some cases there is difficulty in fixing points on them. In such instances positions were determined by pacing or time allowance to some known point. In general, however, the maps proved better than could have been expected, and the shore could be located quite accurately on them. Unfortunately no contoured topographic maps have yet been prepared of the province, so that elevations had always to be determined from known levels, such as lake Ontario or points on railways or canals. At a distance from such bases the aneroid was used, but in all important determinations the hand level or a surveyor's level was employed. The railway levels are not absolutely reliable, however, Davenport station, northwest of Toronto, having been proved to be 8 feet lower than the published altitude.

In the mapping special attention has been given to the main shore and the bars continuing it across the mouths of bays, but the shore of the larger bays has generally been mapped also when well enough marked to be followed.

NIAGARA RIVER TO HAMILTON

The cutting of the gorge at Niagara from the front of the escarpment at Queenstown heights is generally held to have begun when the water fell from higher levels to the Iroquois stage, but the lower gorge from the heights toward lake Ontario has not generally been considered in the treatment of the subject. For reasons which will be given later, it is probable that the water level at the beginning of the Iroquois time was much lower than at its end, and that the cutting of the river channel through boulder clay and Medina shale toward the north began at the same time as the main fall commenced its work on the escarpment to the south; but to what extent the channel was complete when the last and highest stage of lake Iroquois was reached is uncertain.

The fine bar at Lewiston, with its wonderfully cross-bedded gravels dipping to the south, represents, of course, the final stage of lake Iroquois and now stands between the contours of 360 and 380 feet above sea, according to the United States survey, or from 114 to 134 feet above Ontario. By hand level I made the highest point at the end of the bar toward the river 122 feet above it, or 124 feet above Ontario; but Doctor Gilbert, as quoted by Doctor Spencer, makes it 139 feet, having probably found some higher beach level which was overlooked by myself.

On the Queenstown side gravel deposits were not seen, but the waterline is clearly marked as a cut terrace at the foot of the Niagara escarpment, just to the north of the road leading to Saint Davids. It keeps this position for a mile or two west, when the Saint Davids valley cuts far back into the escarpment, and the shore cliff sinks almost to the Iroquois level with a gently rolling plain to the south, and these conditions last as far as Homer, where gravel bars commence, the shore cliff having disappeared, and a shallow bay is cut off to the south.

From Homer to the city of Saint Catharines the gravel bar grows more extensive, and at Saint Catharines it crowds the river, followed by the old Welland canal, a mile or two westward, much as the Don and Humber have been forced westward by gravel bars near Toronto, on the north side of Ontario. At Saint Catharines hand leveling from the Grand Trunk railway station, which is just below the shore cliff, makes the top of the bar 122 feet above lake Ontario. Beyond this the usual low shore cliff extends to the west as far as Fifteen-mile creek, where a ravine discloses stratified gravel, and then to Jordan, where the Niagara escarpment once more forms the shore for a mile or two. From Jordan to Beamsville there is little change, except that the escarpment withdraws again, the clay cliffs grow higher, and the soft Medina shale sometimes shows beneath the almost stoneless till.

West of Grimsby the Niagara cliff once more rises immediately above the Iroquois plain and continues to within a mile or two of Stony creek, where there is a bay-like recession with gravel bars reaching west toward a bold promontory of the escarpment near Hamilton.

In general this part of the old shore is very straight, and the subaqueous Iroquois plain slopes gently northward toward lake Ontario. The main road follows the shore the whole way, partly at the foot of the cliff, partly on top of the low clay shore cliff, but where possible on the gravel bars in front of the bays. The silt and clay of the old lake bed to the north provide one of the finest fruit growing districts of Canada.

IROQUOIS BEACH AT HAMILTON

Perhaps the most interesting point on the whole shore of lake Iroquois is found in the vicinity of Hamilton, where the sharp turn takes place from the nearly straight westerly shoreline to the northeasterly trend north of lake Ontario. Doctor Spencer has described the great Dundas bay cut off by a magnificent bar, much as the present Hamilton bay is formed by Burlington beach,* and the Geology of Canada mentions various vertebrate fossils found in the beach deposits,† so that this striking physiographic feature has received a good deal of attention. Originally the stream flowing from Dundas passed the extreme northern end of the great bar, but many years ago a canal was cut across the narrowest part of the ridge and the old channel was filled with a railway embankment. The fossils mentioned in the Geology of Canada were obtained in the cutting for the canal, and the statement is made that Erie clay was found near the level of the lake with sand and gravel above, the bones of mammoth, wapiti, and beaver occurring 70 or 80 feet above the lake.

The mode of construction of this great bar, which is about 3 miles long, generally less than a quarter of a mile in width, and 116 feet high, with marshy ground to the west at the same level as lake Ontario to the east, deserves special attention. From the present water level up to 57 feet it is formed of sand, on which rest about 60 feet of coarsely stratified gravel partially cemented into conglomerate and standing up as steep cliffs above the talus covering the lower part of the bar. How this wall-like mass, sometimes only 100 yards wide on top, was built up from the clay floor beneath the present marsh to the height of 116 feet, with steep slopes on either side, is not easy to explain unless by supposing that its foundations were laid in shallow water, and that layer after layer was added to the bar during a gradual rise of the water. Even then it might be expected that the base would have been much broader than it is. From its narrowest and steepest part, near the canal, the bar runs south and then southeast through the city of Hamilton to the foot of the Niagara escarpment.

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*Spencer: Am. Jour. Sci., vol. xxiv, 1882, p. 415; also Trans. Roy. Soc. Canada, 1889, p. 129 et seq.

†Geol. Canada, 1863, p. 914.

On the south side of the old bay a well defined plain extends from Hamilton to Dundas at about 80 feet above lake Ontario or 36 feet below Burlington heights. At first the plain is of clay overlying gravel, but to the west the gravel runs out and only clay is seen.

A deep railway cutting made some years ago, but now covered in as the Hunter Street tunnel, exposed 30 feet of coarse stratified gravel belonging to the southern end of the bar, followed by 2 feet of brown unstratified clay, evidently an old soil, and 8 feet of blue till. In the old soil quantities of decayed wood, as well as bones of mammoth and other animals, were found. About a mile to the west large pits opened for clay, sand, and gravel disclose the following section:

	Feet.	Feet
Clay making red brick...	6	78
Gravel	30	72
White sand..	5	42
Hardpan..............................	4	37
White sand with mammoth tusks and bones......	0	33
Covered to level of bay......................	0	0

The mammoth remains are not apparently waterworn and we may suppose that the animal which supplied them died on the spot, so that the water level at the time can not have been more than 33 feet above the present lake Ontario.

The whole evidence, from the character of the gravel bar, the finding of an old soil with trees and stumps 32 feet below the top of the gravel, and of unworn mammoth remains 83 feet below it, indicates a great change in water levels during Iroquois times, low water being followed by high water, until in the end the bay cut off to the west was almost as large as the present Hamilton bay and had a depth near the bar of more than 100 feet.

Before the end of the last Iroquois stage a prominent gravel bar was formed near Waterdown, east of Burlington, and extended 2 or 3 miles toward the present Hamilton bay, to a small extent overlapping the bar previously described, which is about a mile to the east.

BURLINGTON HEIGHTS TO TORONTO

From Burlington heights to Toronto the Iroquois shore has much the same features as from Queenstown to Hamilton—a broad, flat clayey surface sloping gently toward lake Ontario, with a low shore cliff of clay or more rarely of shale to the northwest. The shore is nearly straight and runs parallel to the present Ontario shore, but about 2 miles inland.

At Credit river the regular trend of the beach is broken by a deep bay with a bar of gravel cemented to conglomerate at its mouth, and from here to the Humber river, just west of Toronto, there are low shores and gravel bars. Dundas street, the main road of the region, follows the gravel bars, or the low shore cliff, or the terrace at its foot, and the Canadian Pacific railway makes use of it for several miles also.

East of the Humber, at Toronto junction, another gravel bar, 176 feet above Ontario, runs 2 miles westward, crowding the Humber out of its old channel and forcing it to cut a new one through boulder clay and Hudson River shale. It has already entrenched itself 30 or 40 feet in the bed rock, while a small tributary, Black creek, is reexcavating the old valley to the east, disclosing in places 100 or more feet of stratified sand and clay. In the gravel itself many horns and bones of caribou are found, and a number of years ago a Mr Thompson reported finding a stone muller and arrow-head along with such remains, making it very probable that the Indian dwelt on the shore of lake Iroquois much as he did a hundred years ago on Toronto island.

Toronto is mainly built on the sloping Iroquois terrace below a well marked shore cliff of boulder clay. At Reservoir park a small gravel deposit has provided many shells of Campeloma, Pleurocera, Sphærium, and Unio, and a well sunk near the Don river half a mile to the south disclosed similar shells 70 feet below the level of the beach. Except unios reported from the Iroquois beach in New York many years ago, these are the only known organic evidences that the water of those days was fresh. At the well near the Don there was fairly satisfactory proof that the boulder clay and other deposits of post-Glacial and inter-Glacial age had been weathered and eroded before these shell beds were formed.

Where the Don valley crosses the Iroquois shore there is a gap of about 2 miles, a wide bay extending to the north, and beyond the river, at York or East Toronto, another gravel bar, still larger than that at Toronto junction west of the city, extends westward from Scarboro heights. The Don has evidently been elbowed westward in much the same way as the Humber and has been forced to cut a new channel, which in places is trenched 15 or 20 feet into the bedrock. The East Toronto bar, which has disclosed a mammoth tooth and caribou horns, stands from 186 to 196 feet above lake Ontario.

Scarboro to Colborne

Near the east end of the gravel bar cutting off the Don bay the shore cliff of lake Iroquois is from 50 to 150 feet high, cut in a great spur reaching southward from the morainic ridge called the Oak hills, and here for half a mile the waves of lake Ontario have eaten back the Scarboro cliff so far as to destroy the old beach. East of Scarboro heights the shore bends to the northeast till it is nearly 8 miles from Ontario near Whitby, but one of the boldest promontories on the whole shore projects southward again at Newtonville, beyond which there is another deep bay reaching 7 miles from lake Ontario with a drumlin island offshore not far from Port Hope. By the hand level the bar at Quays gravel pit, north of Port Hope, is found to be 311 feet above Ontario.

From this point the beach is carved in the bold morainic ridge crossing central Ontario, and as far as Colborne presents the usual characters in such a position—bold cliffs of boulder clay 50 or 100 feet high with small gravel bars across the depressions in the hills. The whole beach from Niagara river to Hamilton and Colborne is conspicuously a unit, with no distinct splitting up into higher and lower bars. We may suppose that the old bars rose a few feet above water, as we find to be the case on the shore of lake Ontario, but, as on the modern lake, the water level probably averaged not more than 5 feet below the top of the bars. To the east of Colborne, however, the beach loses its unity and different water levels show themselves.

Colborne to Trenton

At Silver lake, 3 miles northeast of Colborne, on a promontory facing southeast, there are massive bars at three levels, the highest 28 feet above the lowest, and as along the previous coastline the difference between neighboring bars has never been found to exceed 10 feet, we must conclude that there was an actual shifting of water levels to cause so great a divergence here. Silver lake is really a small bay cut off from lake Iroquois, and now draining north through a valley crossing the moraine, and turning east into Trent river, instead of emptying, as one would expect, into lake Ontario two miles and a half away and 360 feet lower down. Evidently a narrow strait cut off a large group of hills between Silver lake and Trenton in Iroquois times, and heavy wave action from the broad lake to the south piled up gravel enough to cut off communication in that direction, leaving the modern stream to find its way northward.

North of Brighton gravel bars occur at different levels once more, and this is still more pronounced 3 miles northwest of Trenton, where the hills end sharply in a bold promontory facing eastward, while the boulder strewn terrace beneath slopes gently away on the north, east, and south. The level of the main beach near Trenton was determined by Doctor Spencer a number of years ago, but in different publications he gives the figures differently (386 and 436 feet above Ontario), so that a line of levels was run by myself from the bay of Quinte to fix this important point, the results being as follows:

	Feet
Highest terrace (faint)	450
Well marked terrace	441
Rear of gravel beach	386
Lower bar on road	374
Rear of boulder pavement	339

The best marked water level is the one at 386 feet, and this is the one adopted by Doctor Spencer in his latest writings. His earlier estimate, unless a misprint, may represent the terrace at 441 feet in the previous table. The difference in level between the lowest and the highest beach is 76 feet and between the two best marked water levels 55 feet, so that there is an increased divergence as compared with the beaches at Silver lake.

Rounding the point of the hill, the shore runs westward; but, owing to the narrow channels between the shore and islands to the north, it is hard to follow and can not be mapped with absolute certainty until a contoured topographical map of the region is available.

From the hilltop above the beaches mentioned above a number of islands can be discerned to the north and northeast.

Islands to the North and Northeast

The shore of the bay to the north of the large island between Silver lake and Trenton runs in a general way northward to Hastings, on Trent river, a little below Rice lake, and an archipelago of islands of various sizes—some mere drumlins, others from a mile to 7 miles long—extends to the great bend southward of the Trent on its way to the bay of Quinte. Twelve of these islands have been wholly or partially mapped, but some were probably submerged in the earlier, highwater stages of lake Iroquois and have only the lower beaches, while one or two drumlin shoals, flat topped and covered with boulders, scarcely reached the surface at the lowest stage of water.

Of these islands only a few need be treated separately. North of Campbellford is a long island standing out boldly toward Crow bay, just where the Trent turns south, with a steep slope from the river to a series of beaches which were determined by hand level as being respectively 432, 442, and 475 feet above lake Ontario. The work was done on a rainy day, and higher beaches may have been overlooked, since Doctor Gilbert tells me he has found beaches here or a little to the southwest 90 feet apart, instead of only 43 feet.

To the north of this island for several miles no land stands high enough to receive the beaches, nor is there any hill high enough for this to the east, so far as can be seen. Near Frankford, to the southeast, a small island displays four beaches, the highest 47 feet above the lowest.

The most interesting islands, however, are two on the east side of Trent river—one between Frankford and Stirling and the other near West Huntingdon. The first is 6 miles long and runs northeast as a central ridge bordered by a terrace. About the middle of the island but on the northwest side is Oak Hill lake, a bay of lake Iroquois cut off by a massive gravel bar and without an apparent outlet. It is said to be 43 feet deep and to have contained only minnows before it was artificially stocked with fish. This curious and beautiful lake stands as an authentic remnant of the Iroquois water now 435 feet above lake Ontario. By hand level it was shown that a boulder pavement exists at 398 feet and gravel bars at 414, 430, and 466 feet, the last being the very well defined bar which incloses Oak Hill lake toward the northwest.

Three miles northeast, at the end of the island, is a small pond inclosed in the same way, and near by to the north beaches stand at 450, 460, and 475 feet as leveled from Madoc junction, indicating a considerable rise per mile, which, however, will be discussed later.

The last island can be seen 5 or 6 miles to the northeast, a little beyond West Huntingdon station and just southeast of mile 19 on the railway to Madoc. Here gravel beaches were leveled at 440, 492, and 498 feet above Ontario, the last forming the summit of the island, which must have been under water at the highest stage of lake Iroquois. The level of 498 feet is the highest above lake Ontario recorded in the province, and this small island is about 140 miles in a direction 57 degrees east of north from Hamilton, at the southwest end of the old lake, where the single beach is only 116 feet above Ontario.

It should be mentioned that the levelings in connection with the islands referred to above are probably only approximately accurate, since the hand level was used, and the distance from points of known elevation was occasionally 2 or 3 miles; but the differences in level between the beaches at any given place were reasonably correct and the elevations given can not be far wrong.

Region North of Trent River

While the island north of Campbellford displays splendid gravel beaches, evidently formed under powerful wave action from the east, the opposite hills to the north of Trent river, near Havelock, have not disclosed any well marked beaches whatever after numerous visits to promising hills, often of glacial drift, well adapted to record a beach.

Search has also been made north of Blairton, and of Madoc, near Eldorado and Malone, but with no success. In the last locality the hills are quite high enough to receive the beaches, the railway reaching 700 or 800 feet above the sea, though keeping to the valleys. The hills are largely rocky—Laurentian more or less capped with flat Ordovician limestones—but there seems to be drift enough to record the beaches if they had been formed. Reluctantly the conclusion was reached that the beach does not extend beyond Havelock toward the northeast; probably because the region was occupied by ice.

Southwest of Havelock and about a mile west of Trent bridge, a distinct gravel bar is found 75 feet above the river, or 436 feet above Ontario, and others occur at about the same level between this and Hastings, all probably equivalent to one of the lower Iroquois beaches found on the island north of Campbellford at 432 or 442 feet. A bay must have extended southwest along the Trent valley, including Rice lake, but it was so narrow that evidence of wave action is almost wanting. As Rice lake is 370 feet above Ontario, and the distance from Trent bridge to its southwest end is 30 miles nearly in the direction of tilt of the old beach, which is at a rate of not less than 3 feet per mile in this region, the bay can hardly have extended to its extreme end. Its surface must have dipped beneath the present plane of Rice lake, not far from the mouth of Otonabee river, and as the lake is only 30 feet deep at the deepest point, the southwest end of the bay must have fallen 2 or 3 miles short of the present end of the lake.

As the southwest end of Rice lake is only 4 or 5 miles from Quay's gravel pit, on the Iroquois beach north of Port Hope, it is evident that the morainic hills to the northeast formed a large peninsula in lake Iroquois connected with the mainland by a rather narrow isthmus.

Lake Peterboro

It was thought at first that Rice lake bay extended an arm along the valley of the Otonabee, which is the northern equivalent of Trent river, as far as Peterboro, but an examination of the ground shows that a short stretch of river confined between drumlins and moraine ridges separated the two bodies of water, so that lake Peterboro must be recognized as distinct from lake Iroquois.

The lake covered a clay flat toward the south and reached to the north end of the city of Peterboro, a length of about 10 miles. Here a river much larger than the Otonabee entered it from the north, piling up delta deposits of coarse gravel and sand, the highest terrace reaching 432 feet above lake Ontario. This great river was probably the outlet, at least for a time, of lake Algonquin, before the uplift to the northeast sent its waters round by Niagara falls. It may be, however, that Niagara falls began while lake Peterboro and the Rice Lake bay of Iroquois were still ice covered, and that the drainage of lake Algonquin through lake Peterboro came after Niagara falls had been in existence for some time. The Trent Valley canal, now under construction by the Canadian government, will, in a sense, renew this ancient connection between the upper and lower lake.

BEACH LEVELS ON THE NORTH SHORE OF LAKE IROQUOIS*

	Feet.	Miles north 20 degrees east
Hamilton	116	0
Waterdown	123	4½
Cooksville (Spencer)	154	25½
Toronto junction (1 mile west, at 32, the bar reaches 179)	176	33
Leaside (Canadian Pacific railroad just east of Toronto)	188	36
York (Grand Trunk railroad just east of Toronto)	186	36½
York (a mile southeast, measured from lake Ontario)	196	37
Kingston road (Spencer)	213	42½
Quays siding (north of Port Hope)	311	72
North of Colborne (Spencer)	356	79½
Silver lake (northeast of Colborne) 360 (aneroid)	388	81
Northwest of Trenton	(374), 386, 441, (450)	89½
Oak Hill lake	414, 430, 461	100½
Southwest of Havelock	436	102
Island west of Madoc junction	450, 460, 475	102½
Island north of Campbellford	432, 442, 475	103
(Gilbert puts highest beach 90 feet above lowest = 522.)		
Island near West Huntingdon	(440), 492, 498	108

The elevations at Toronto junction, southeast of York and northwest of Trenton, were determined with a surveyor's level; the others, where not otherwise noted, were determined by hand level from known points. Levels inclosed in parentheses are more or less doubtful. In all cases the levels given are from the top of gravel bars, probably on the average 5 feet above the usual water level.

IROQUOIS BEACH, IN NEW YORK STATE

Within the bounds of New York state the Iroquois beach has been traced mainly by Doctor Gilbert,† but the region has been worked over partly by Professor Fairchild also, who examined specially the beaches into which the old shore is split up north of the Rome outlet with a view to settling the question of the deformation of the shore during the existence of lake Iroquois.* The portion of the Iroquois shore beyond the province of Ontario given on the accompanying map is copied from the one published by the New York state survey, which appears in the main to be taken from Doctor Gilbert's earlier work. It is of special importance as showing the old outlet of lake Iroquois past Rome, through the Mohawk valley into the Hudson. From Lewiston to Rome the old shore appears to be a unit, as it was found to be on the Ontario side as far as Colborne, and its general characters seem to be much like those described in former pages. A great bay opened southeastward with many inlets and islands, a counterpart of the island-filled bay between Trenton and Peterboro on the north side. Beyond the Rome outlet toward the north the shore is broken up into two or more beaches, as given in tabular form by Professor Fairchild, but he was unable to trace continuous shorelines spreading more and more widely apart as one advances north, and concluded that a shifting of water levels during the existence of lake Iroquois is not yet proven.† He is more inclined to think that the different levels of the gravel bars result from the lowering of the Rome outlet and not from the tilting of the basin. Against this, however, is the fact of the unity of the beach from the Rome outlet west to Hamilton and northeast to Colborne. A lowering of the outlet should have affected the whole shore, and not only the portion northeast of a line between the Rome outlet and Colborne.

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* All elevations are above lake Ontario.

† Sixth Ann. Rept., State Reservation at Niagara, 1888-1889, pp. 67-71.

On each side of lake Ontario we find this old shore split up into separate beach levels toward the northeast. The separate beaches are very distinctly marked up to points near Watertown in New York and Havelock in Ontario, but beyond these points the Iroquois shore can no longer be traced with certainty. The first recognition of the splitting up of the beach into several levels, both in New York and Ontario, to the north of the outlet is due to Doctor Gilbert, who discovered the Rome outlet and connected the divergence of the beaches with a tilting of the basin during Iroquois times.

TILTING OF THE IROQUOIS BEACH

That the Iroquois beach is no longer horizontal was proved long ago by Doctor Spencer north of lake Ontario and Doctor Gilbert south of it. The direction of uplift has generally been stated as north 27 degrees east, but this does not accord with the facts north of lake Ontario, and in any case we must suppose that the isobases are curves of long radius, with the area of greatest uplift at the center, so that the direction must vary in different parts of the Great Lakes region. The Hamilton beach (116 feet above lake Ontario) was the lowest point recorded on the shore, and the beaches at Trenton, in Ontario (at 386 feet), and one near Adams Center, in New York (at 411 feet), or Prospect farm (at 484 feet) were the highest noted. Doctor Spencer estimated the rate of differential elevation at 1.6 feet per mile between Hamilton and Carlton (now Toronto junction) and 5 feet per mile in the Watertown region, with intermediate rates between.

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* Pleistocene Geol. Western New York, 1900; from Twentieth Rept. U. S. State Geologist.

† Ibid., p. r 111.

During the present survey of the Iroquois beach a number of elevations have been determined, partly in old localities, but largely in new ones, and some changes in the probable rate and direction of the warping result from these determinations. In general the top of gravel bars has been taken as giving most definitely the old water levels, though these were no doubt often a few feet above mean water level, perhaps 5 feet on the average, as we find to be the case on the shore of lake Ontario at present. Lake Iroquois was, of course, larger than Ontario, and wave action must have been somewhat more powerful, but the old bars can hardly have risen more than 10 feet at most above the level of the water, and may be assumed to have a fairly uniform relation to that level on all parts of the shore. The foot of shore cliffs is more uncertain, owing to the slipping and creeping of clay and other loose materials since Iroquois times.

An attempt has been made to work out isobases with somewhat conflicting results, but, using my best determinations of the water levels, the most probable direction of elevation is found to be north 20 degrees east, and this will be assumed to be correct in the following work.

In determining the rate of deformation of different sections of the Iroquois beach three equal subdivisions have been made—from Hamilton to York, from York to Quays, near Port Hope, and from Quays to the last point where the beach has been found.

At Hamilton the beach stands 116 feet above Ontario, and at York 190 feet (as averaged from three determinations at different points on the old bar), the difference of level being 74 feet in a distance of 36½ miles, as measured in a direction north 20 degrees east, giving an average inclination of 2 feet per mile.

Between York (190) and Quays gravel pit (311) there is a difference of 121 feet in 35½ miles, averaging 3.4 feet per mile. Beyond Quays, or rather beyond Colborne, a few miles to the northeast, the beach is found to be split up, as shown in earlier parts of this paper, and the question of the amount of deformation per mile becomes much more complicated.

That there is a divergence in the beaches toward the northeast is certain, but the amount of divergence appears to be less regular than it should be, though more regular than seems to be the case between Richland and Watertown, in New York, as measured by Professor Fairchild.

The question arises which of the several levels should be used in comparing with the single beach southwest of Quays, the lowest, the highest, or some intermediate beach? If we suppose that the northeast end of the basin rose during Iroquois times, as seems probable, evidently the continuation of the single beach found to the southwest must be sought for in the lowest of the divided beaches, unless that resulted from a cutting down of the outlet, as suggested by Professor Fairchild. In this case, however, the beach should be split up all round the lake, and not simply at the northeast end. It has been assumed therefore that the lowest well marked beach at points northeast of the dividing line corresponds to the southwestern beach. Unfortunately the lowest beach at some points does not fit very exactly in level with the lowest at other points.

Between Quays and Trenton, a distance of 18 miles in the direction north 20 degrees east, the inclination of the lowest well defined beach works out to 4.17 feet per mile. On the island north of Campbellford, 31 miles north 20 degrees east of Quays, the inclination, as compared with Quays, is 3 9 feet per mile, but as compared with Trenton, only 3.41. The island west of Madoc junction, at its northeast end, gives, when compared with Quays, an inclination of 3.92 feet per mile, but as compared with Trenton, 5 feet per mile; but for the lowest beach at Oak Hill lake, 2 miles southwest, on the same island, the corresponding figures are 3.61 and 2.55 feet per mile.

For the farthest island to the northeast (near West Huntingdon) we have only the lower beaches, the island having been submerged in the earlier times of high water. Taking the distance north 20 degrees east of Quays at 36 miles and omitting a doubtful lowest beach at 440, which would give an inclination of 3.58 feet per mile, we have, as compared with Quays, deformations of 5 and 5.2 feet per mile for the two well formed beaches at 492 and 498 feet above Ontario.

The inclination of the lowest well defined beaches to the northeast of Quays runs, as given above, from 3.61 to 5 feet per mile, with an average of 4.17 feet, in contrast with 2 feet per mile on the southwestern stretch and 3.4 per mile for the intermediate part. If the deformation increases at a uniform rate toward the northeast, and if the lowest distinctly marked beach is considered to be the continuation of the beach to the southwest of Quays, we should expect, however, a tilt of about 5 feet per mile, instead of an average of 4.17 feet.

The inclination of the highest beach is still less satisfactory, working out at 7.22 feet per mile between Quays and Trenton and only 5.3 for the island north of Campbellford, according to my figures, though Doctor Gilbert's separation of the highest from the lowest beach by 90 feet gives an inclination of 6.8 per mile. The West Huntingdon island does not reach the higher water levels, and so is unavailable for our present purpose.

From the figures given above it will be seen that the rate of divergence of the highest from the lowest beach is not very uniform, though in general the spreading apart, with increased distance from the starting point, is clearly indicated. At Silver lake, 9 miles from Quays, it is 28 feet, or 3 feet per mile. At Trenton, 18 miles away (in the direction north 20 degrees east), it is 55 feet for the two best defined levels, or 3 feet per mile. On the island north of Campbellford, at 31 miles, it is only 43 feet by my determinations, but 90 feet by Doctor Gilbert's, the latter giving nearly 3 feet per mile.

RELATION OF THE IROQUOIS BEACH TO THE ROME OUTLET

Doctor Gilbert showed long ago that a river channel drained lake Iroquois through the Mohawk valley toward the Hudson, and drew the inference that if the tilting of the region was in progress during the existence of lake Iroquois, its effects should be recorded in the beaches. The splitting up of the gravel bars to the northeast he looked on as evidence in favor of this conclusion, and he expected that proofs of lower water levels than the last one would be found near Hamilton, at the opposite end of the lake. Doctor Spencer, on the other hand, believed that the Rome outlet was of little importance, and that the "Iroquois water," as he preferred to call it, was an arm of the sea, an extension of the gulf of Saint Lawrence; perhaps freshened, however, by the rivers flowing into it, as some of the great Siberian rivers are stated to freshen the gulfs into which they flow.

If the Iroquois water was connected with the sea—that is, stood at sealevel—and the proved elevation toward the northeast was unaccompanied by a depression toward the southwest, and there is no known evidence of such a depression, the effect of the differential elevation of the region during the lifetime of the "water" would be to form a series of continuous beaches running the whole length of the shore, but spreading farther and farther apart toward the center of most rapid elevation to the northeast. There could be no crossing of the highest and lowest beaches.

In earlier parts of this paper evidence has been given of the existence of old land surfaces far below the Iroquois beach near Hamilton, and also near Toronto, and likewise of a splitting of the beaches to the northeast of a line running from the Rome outlet to Quays or some point near it; but it is desirable to present the evidence for this in a more definite way than has been done before.

If the isobases are represented as straight lines at right angles to the direction of greatest inclination, north 20 degrees east, as shown by my levelings, an isobase passing through the Mohawk outlet runs a little south of Quays gravel pit. The direction formerly given for the greatest uplift is north 27 degrees east, which would send the isobase of the Mohawk outlet 9 miles to the north of Quays, through Silver lake. At this point the beach is already split up into three gravel bars, the highest and lowest 28 feet apart, so that theoretically the line must pass some distance to the southeast, according better with the direction north 20 degrees east.

Taking 3 feet per mile as the amount of spread between Silver lake and Trenton, a distance of 9 miles, the two best water levels being here 55 feet apart, the lines will converge at Quays, confirming the evidence obtained in other ways in favor of that point as the node. We may conclude, then, that the line of no separation of the beaches runs from the outlet near Rome approximately through Quays, which is about 6 miles north of Port Hope.

If we consider that the amount of divergence between the highest and lowest beach to the northeast of the fulcrum is diminished toward the southwest proportionately to the diminution in the rate of deformation of the latest beach, namely, as 4.17 to 3.4, we shall have a rate of separation of 2.45 feet per mile; so that at York, just east of Toronto, the lowest beach, now buried of course beneath the later beach formations of lake Iroquois, should be about 87 feet beneath the highest. Continuing the divergence for the 37 miles between York and Hamilton at a rate proportionate to the deformation of the latest beach, which is 2 feet per mile, the highest and lowest beaches would spread 1.44 feet per mile, or about 52 feet. Adding this to the 87 feet of spread between Quays and York, the total divergence should be 139 feet, which would put the first level of lake Iroquois at Hamilton 23 feet below the present level of Ontario at that city.

It will be understood, of course, that the data derived from the spreading of the beaches northeast of the hinge line are not absolutely certain, and also that the supposition of a southwesterly divergence proportional to the rate of deformation of the latest beach is hypothetical, though very probable; so that the results just given can be looked on only as rough approximations to the truth. They are, however, corroborated to a considerable extent by the evidence given earlier of erosion and shallow water shells, found 70 feet below the Iroquois level at Toronto, and the presence of unworn mammoth tusks and bones 83 feet below the Iroquois gravel bar at Hamilton. The peculiar wall-like character of Burlington heights also may be considered as pointing in the same direction, suggesting a beginning in shallow water and steady upgrowth as the water rose.

Taking the evidence as a whole, it will be admitted as almost a certainty that the deformation of the land and the corresponding tilting of the basin progressed during the existence of lake Iroquois, and that the amount of differential elevation toward the northeast was important, possibly as much as 250 feet between the extreme ends of the basin and certainly not less than 140 feet. The total deformation, including that which has taken place since Iroquois times, can hardly be less than 500 feet in a distance of 108 miles along a line running north 20 degrees east, and something should no doubt be allowed for differential elevation to the southwest of the Ontario basin, though the amount of the latter is uncertain.

The whole amount of deformation must, however, be less than the elevation of the highest part of the Iroquois shore above sealevel, about 744 feet at the West Huntingdon island, otherwise the surface of the Iroquois water at its earliest stage would have been below the sea, which is impossible with the Niagara river pouring into it.

It is probable that lake Iroquois began its existence much nearer to sealevel than lake Ontario is now, and some day its initial elevation may be determined approximately by tracing the slope of the Mohawk river channel to its outlet at some marine terrace in the Hudson valley.

TIME ESTIMATES

As shown by Professor Fairchild, the amount of warping of the land during and since Iroquois times is so great as to demand a very long time if the present rate of differential elevation worked out by Doctor Gilbert for the Great lakes is made the standard.* Taking the estimates given above and assuming the rate of 0.42 feet per hundred miles per century, the minimum differential elevation of 140 feet in 108 miles implies more than 30,000 years for the duration of lake Iroquois, and the maximum of 250 feet requires nearly 55,000 years. If the total differential elevation of not less than 500 feet from the beginning of Iroquois times to the present is taken as correct, more than 100,000 years must have elapsed since the ice set free the Mohawk outlet.

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* Pleistocene Geol. Western New York, 1900, p. r 112.

The usual estimates of the time since the retreat of the ice allowed Niagara to begin its work, 7,000 to 35,000 years, indicate very different rates of deformation. If we allow one-half the time since the beginning of Niagara for the lifetime of lake Iroquois, and this is clearly too high an estimate, the tilting during the 3,500 years would progress at the rate of 1 foot in 14 or at most 25 years. Taking the other extreme of 17,500 years, the rate of elevation would be from 1 foot in 70 to 1 foot in 125 years. For the minimum total deformation of 500 feet the time allowed per foot would be from 14 to 70 years. Whether such a rapid rate of uplift as this should be assumed or whether the usual time limits for the work of Niagara falls should be extended is a question into which we need not enter here, but the lower limit of 7,000 years has always seemed to me quite insufficient for the formation of the Iroquois beach, of the thick marine post-Glacial deposits of eastern Ontario, and of the present mature shore forms of lake Ontario.

It is now many thousand years since the Labradorean ice-sheet began to be removed from this region, and it is a considerable number of thousands of years since it totally disappeared. If the removal of the load of ice occasioned the elevation of the region, which is highly probable, we may suppose that the rate of elevation was formerly more rapid and is now slowing down before ceasing altogether when equilibrium is reached. During Iroquois times, although the load had vanished from the southwestern part of the region, some hundreds of feet of ice still blocked the Saint Lawrence, but thousands of feet must have been removed already from the region to the northeast, giving a sufficient cause for rapid elevation in that direction.

Climate and glacial Relationships

All the conclusions reached in this paper point toward the presence of a dam of ice across the northeastern end of the Iroquois basin from the neighborhood of Havelock to a point on the Adirondacks somewhat northeast of Watertown, New York, the shore of ice having a length of more than 100 miles and a thickness of not less than 500 feet where the Saint Lawrence now passes out of lake Ontario. The exact position of this ice barrier is uncertain, but the finding of the lowest, and therefore latest, beach near Trent Bridge, southwest of Havelock, and not the higher, earlier ones, suggests that the ice occupied that point in the earlier stages of lake Iroquois, but had retired from it before the end. Probably careful search may yet disclose glacial deposits in connection with one or other of the beaches into which the Iroquois is split up in that region, but this has not yet happened, so that we are reduced to inference in settling the position of the ice-front.

It is natural to suppose that the ice withdrew slowly from the Ontario basin, at first holding back the water poured in from Niagara at different levels above that of lake Iroquois, and producing the channels which Professor Fairchild has mapped in New York state, until finally the Rome outlet was reached, beyond which the foothills of the Adirondacks prevented any lower point of drainage for a long distance. The time taken to retreat from the Rome outlet to the next lower spillway between the northern flank of the Adirondacks and the shrinking ice-sheet to the north fixed the duration of lake Iroquois. I am not aware that the most westerly point where the waters began to escape past the ice-front has yet been observed, but to determine its position would be of great interest as giving an idea of the rate at which the ice retreated across a given distance. Whether the ice withdrew northward with a front extending approximately east and west or southeast and northwest is also a matter of importance. If it did so, the lower Saint Lawrence valley must have remained blocked after the Champlain valley afforded a second outlet toward the Hudson. This assumption would require a retreat of somewhat more than 100 miles from the vicinity of Watertown before a lower outlet would become available, and would imply a rate of retreat of only one mile in from 35 to 175 years, according to the usual time estimates. However, there may have been a long halt or halts during the existence of the lake. If the retreat was somewhat uniform from the Rome outlet, the highest beaches should begin to disappear, say between Constantia and Richland, beach after beach being lost, until finally the lowest of all should extend to the first spillway past the Adirondacks. That this succession will ever be traced is, of course, somewhat improbable.

As to the climate on the shores of lake Iroquois and the temperature of its waters, we have only meager information. The mammoth lived at Hamilton and at York, near Toronto, and the caribou was very common at Toronto junction, both animals of a relatively cold climate; and Professor Penhallow has named specimens of wood from an old soil 30 feet below the Iroquois bar at Hamilton *Larix americana* and *Picea* (probably *nigra*), trees of a cool, but not necessarily very cold, climate. The shells found in Iroquois beach gravels at Toronto are of species still living in our waters.

The shore of ice to the northeast must have kept the water cold, but perhaps no colder than that of lake Superior at present, where the temperature is stated to be about that of greatest density. Lake Superior has a marked effect in chilling the summer heat on its immediate shores, but the effect does not extend very far inland.

On the whole, we may suppose a cold temperate if not a subarctic climate in the region during the life of lake Iroquois, which would account for the slowness in melting of the ice-sheet which shut it out from the Saint Lawrence valley, and so give a reason for the great permanence of this ice-dammed lake.

If the differential elevation toward the northeast, which it has been shown took place during the existence of lake Iroquois, was due to the unloading of the land in that quarter by the removal of ice, we must suppose that a great part of the original thickness of the ice-sheet had already vanished, not only toward the edge, but also toward the center of accumulation, for the tilt is greater toward the northeast than toward the southwest. This explanation of the relationships is opposed to Mr Warren Upham's view that the ice toward the end of the glacial period oscillated considerably, presenting a steep front toward a region having a relatively warm climate. The considerations just brought forward indicate, on the contrary, a great thinning of the ice-sheet as a whole, accompanied, no doubt, by a stagnant condition of the edge of the ice, but with a cool climate in the adjacent land, causing only a slow rate of melting.

Summary

The Iroquois beach in Ontario can be followed without important interruptions from the Niagara river to Hamilton, and then northeast to Colborne as a single shoreline of a very well marked kind. From the evidence of old soils, the bones of mammoths, etcetera, and the structure of gravel bars and other deposits at Hamilton and Toronto, it is certain that the earlier levels of lake Iroquois toward the southwest end were 80 feet or more below its last beach.

From Colborne east and north the shore is split into several beaches, which are more widely separated as one advances northeast, though not in a very regular way. The beach appears on promontories and islands as far as Trent bridge near Havelock on the north and West Huntingdon on the northeast, but can not be traced farther, though high enough hills with a suitable surface occur in the region. This is probably because an ice-sheet covered the region to the east and north.

The direction of greatest inclination is north 20 degrees east, and an isobase drawn at right angles to this from the Rome outlet cuts the northern shore at Quays, near Port Hope, about at the point where the beach begins to split up. On the south and east sides of lake Iroquois the same relations exist, the old shore being a unit as far east as the Rome outlet, but split up into several beaches to the northeast.

The best explanation of these facts is found in the theory of differential elevation toward the northeast during Iroquois times. The deformation in a direction north 20 degrees east of the latest beach from Hamilton to York, near Toronto, is 2 feet per mile; from York to Quays, near Port Hope, where the beach begins to split up, 3.4 feet per mile, and from Quays to the West Huntingdon island, the last point where the beach has been observed, it is 4.17 feet per mile, if the average of the lowest well defined beaches of the series is taken as its continuation. The splitting up of the beaches between Quays and Trenton is at the rate of 3 feet per mile, but beyond this toward the northeast the highest beaches are uncertain or may be entirely absent.

Continuing the division of the highest and lowest beaches southwest of the isobase passing through the Rome outlet, and assuming a separation proportional to the amount of deformation in that part of the old shore, the lowest beach at Hamilton must have been 139 feet below the highest, or 23 feet below the surface of lake Ontario.

At the rate of differential elevation of 0.42 per 100 miles per century, lake Iroquois lasted from 30,000 to 55,000 years, and the whole period from its beginning to the present can not be less than 100,000 years; but the rate may have been more rapid at earlier stages, diminishing the necessary time. Seven thousand years are, however, entirely too short a time for the events since lake Iroquois began, and even 35,000 are scarcely long enough.

The climate was probably cold temperate or subarctic, and the ice-dam melted very slowly from the Saint Lawrence valley, though already greatly thinned toward the northeast and nearly stagnant at the edge.

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POST-GLACIAL CHANGES OF ATTITUDE IN THE ITALIAN AND SWISS LAKES

BY FRANK BURSLEY TAYLOR

(*Presented before the Society January 1, 1904*)

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INTRODUCTION

During a trip abroad in the summer of 1894 the writer spent about two weeks studying the lakes of northern Italy in search of evidences of change in the relative attitude of the lakes and the land. In the autumn part of another week was spent in similar studies on lake Geneva and two days on lake Lucerne. The results attained seem to have some interest not only in their local bearings, but also in their general relations to the Alps. This paper, however, is necessarily of a preliminary nature, for two weeks was much too short a time for an exhaustive study of the four Italian lakes examined.

It was found that all three of the larger lakes of northern Italy—Maggiore, Como, and Garda—formerly stood in different attitudes toward the land from those in which they now stand. Their surfaces were relatively higher at the north and sloped to the south about 1 foot to the mile, as compared with their present surfaces.

It might be thought that the abandoned shorelines of lakes of such magnitude—30 to 37 miles long, and with average widths of from 2 to 5 miles—would show wave-made beaches, but, excepting the southern expanded part of lake Garda, which reaches a width of 10 miles, no certain evidence of wave work was found above the present shorelines. The main evidences of the former attitudes of the lake surfaces are the old delta cones of mountain torrents. The torrents descend from high mountains; their fall is rapid, and in time of freshet they carry large quantities of coarse detritus.

Lake Maggiore attains a depth of nearly 2,800 feet, Como over 1,900 feet, and Garda upward of 1,000 feet. The subaqueous walls of their basins are in some places nearly vertical, in a few places overhanging, and their slope is generally as much as 30 degrees, and is often much more. Such steep slopes afford a poor foundation for delta building. The deltas are relatively steep conical forms, resembling somewhat the alluvial cones of our arid western regions. They are, in fact, compound forms, partly alluvial cone and partly delta. Every torrent of any size has a conspicuous old delta deposit of this kind at its former mouth, and in most of these old deltas the present stream has cut a deep trench in order to reach the lake at its present lower level. In a few cases the old delta has been so warn away by erosion that it was difficult or impossible to find any certain evidence of a former higher lake level.

The Structure of Torrent Deltas

As is well known, deltas are built of sediments arranged in foreset and topset beds. By continual additions of foreset beds at its outer margin or front, a delta grows in horizontal extension; by the addition of successive layers to its top it gradually aggrades or builds up its surface to higher levels. The principal growth is accomplished by the foreset deposits, especially where the offshore slope is steep. As the area filled in by these beds grows larger it forms a platform on which the topset beds are laid down. When the topset beds are composed of very coarse materials, the shape they give to the subaerial part of the deposit may resemble a detrital cone. The torrent deposits of the Italian lakes are mostly of this character.

In the original process of building the old deltas, when they were aggrading, the streams did not enter the lakes through deep trenches in older delta deposits as they do now, but in shallow distributaries choked with coarse detritus and frequently shifting their places. The coarser sediments were mostly dropped in the headward parts of the distributaries and added to the building up of the detrital cones. The greater part of the finer sediments were carried down to the lake to be added to the foreset beds. The coarseness of the detritis and the steepness of the surface slope both decreased toward the lake, so that at the shore the material was mostly pebbly gravel and sand and the slope was more nearly horizontal. A small quantity of sand and fine gravel was deposited at the mouths of the distributaries on the shallow water margin of the deltas, and shore currents and wavelets distributed and rearranged them to some extent along the delta fronts.

Some of the larger old torrent deltas show flattening toward their outer edges quite clearly, giving them the appearance of flat-topped terraces, when seen from the lake, but closer inspection shows the top to be a gentle slope steepening rapidly back toward the ravine. These old delta terraces now stand with bluff fronts facing the lake. The top of the bluff in such a delta is the outer edge of the original flat bordering the shore, and the presence at that place of a layer of sand and gravel may be taken as reliable evidence that the lake stood at that level when the delta was made. These related characters of form and composition were used as the principal criteria for the determination of the former attitude of the lake surfaces.

LAKE MAGGIORE

On lake Maggiore very little evidence of a higher lake level was found in its southern third, south of Pallanza. On the opposite shore of the bay, south and southwest of Pallanza a narrow terrace, mostly very faint but fairly well developed at Baveno and Stresa, stands about 30 feet above the lake, and might suggest wave action, but no certain evidence of such work was seen. It is formed by a lateral blending of small torrent deltas. At Meina and Arona, farther south, there are similar faint forms about 25 feet above the lake. North of Meina a number of sharp gullies descend the drift-covered slope and end at the faint terrace level, 25 to 30 feet above the present shore. On the level plain south of Arona and from there to Sesto Calende, at the outlet of the lake, nothing definite was seen. The east shore, south of Laveno, was not examined. The country on that side and also on the west side below Arona is relatively low, and no streams of any size enter. The cut of the Ticino through the great moraine between Borgo Ticino and Somma was seen from a distance to be deep and narrow. A fine series of terraces, which form an amphitheater around the south end of the lake, are cut on the back slope of the great moraine, and are probably due to ice-border drainage.

Just south of Lesa, which is about half way between Arona and Pallanza, there is a quite extensive deposit of gravel. It has the form of a delta terrace, but from its greater horizontal extent was probably built in shallower water than those farther north. Its flatter part, where the sediments are finest, is now 30 feet above the lake. This part was presumably at or perhaps a little above the old lake surface when the delta was formed. The pebbly gravels composing this terrace are well displayed in the bluffs on the shore back of the old castle, a mile south of Lesa. The lanes which lead down to the castle are on the flat delta surface. Southwest of this is the modern delta and stream bed at a lower level.

Between Pallanza and Intra there is a beautiful level plain. At its

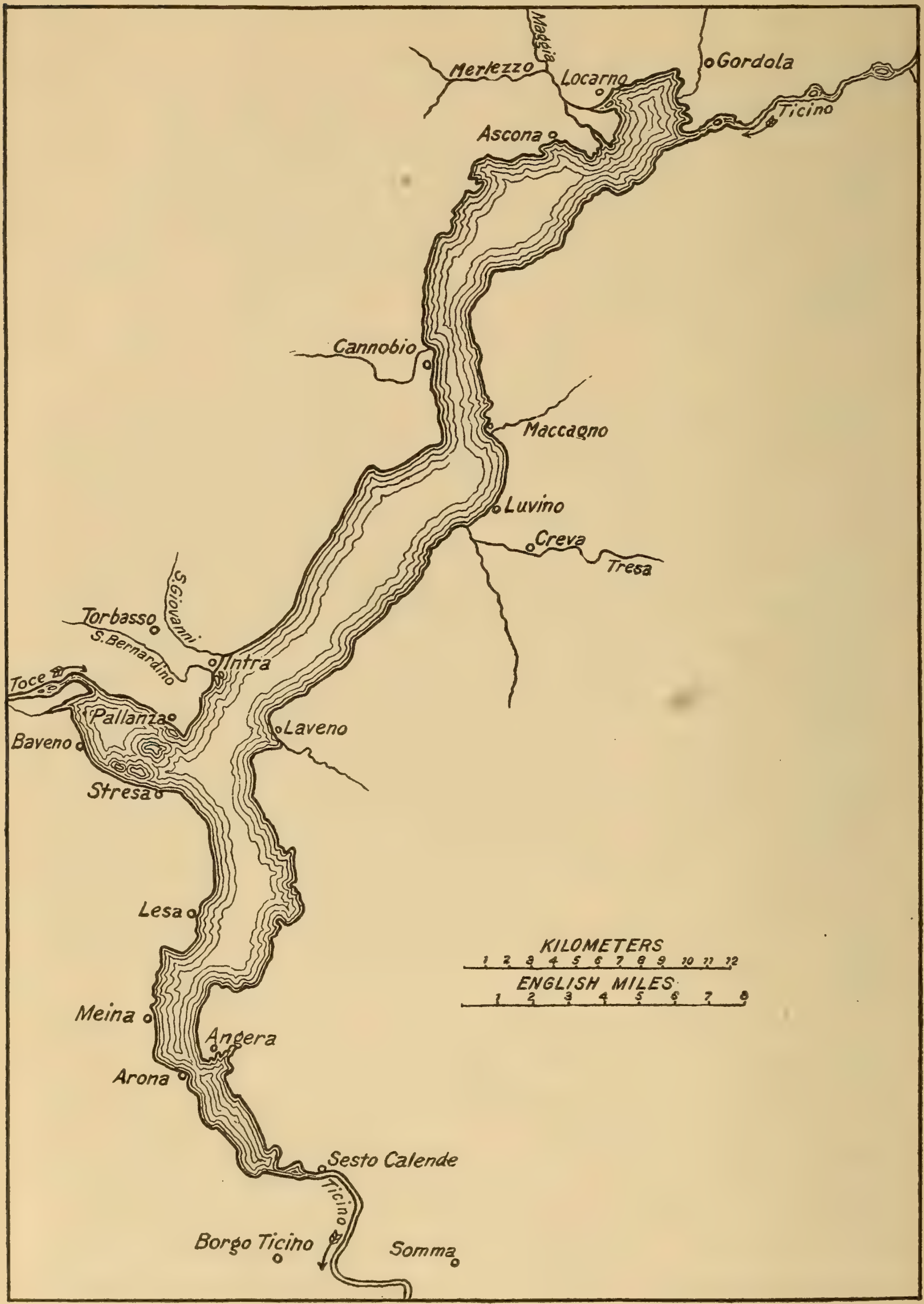
Maggia
Merlezzo
Locarno
Gordola
Ticino
Ascona
Cannobio
Maccagno
Luvino
Creva
Tresa
S.Giovanni
Torbasso
S.Bernardino
Intra
Toce
Pallanza
Baveno
Laveno
Stresa
Lesa
KILOMETERS
1 2 3 4 5 6 7 8 9 10 11 12
ENGLISH MILES
1 2 3 4 5 6 7 8
Meina
Angera
Arona
Sesto Calende
Ticino
Borgo Ticino
Somma

Figure 1.—*Sketch Map of Lake Maggiore.*

north end it merges with the delta of two torrents which enter the lake in parallel beds at Intra. Going up the delta from Intra, on the road between the two streams, the ascent steepens more and more rapidly until near the hamlet of Torbasso, 2 miles back, the deposit becomes a mass of cobbles and small boulders, over 150 feet above the lake. The north stream is the San Giovanni, and the south stream, which is much the larger of the two, is the San Bernardino. From its horizontal extent this delta evidently does not represent a deep filling. My aneroid readings make the level plain south of the San Bernardino about 50 feet above the lake and the same for a similar area in the north part of Intra. The flatness of the plain, the fineness of its soil, and the apparent relation of the plain to the San Bernardino cone suggest that at least the surface or top dressing of the plain is the work of distributaries from the San Bernardino carrying only fine sediments. One mile northeast of Intra there is a small but very prettily formed torrent delta, and its edge at the front of the terrace stands at about the same height as the flat in the village.

The next deposit examined was at Luvino, on the east shore. At this place delta deposits are beautifully developed in terraces at two levels, but the situation and the history of these deltas are quite different from those of typical torrents. The deltas at Luvino are not torrent deltas, but are deposits of what one may call a less strenuous stream, the Tresa, which carries the overflow of lake Lugano. The Tresa descends about 250 feet in 7 or 8 miles, but nearly all of its fall is in its lower half. It receives no tributary torrents, except three or four very small ones in its upper half. The head of the main or upper delta is at the upper mill at Creva, a small village at the falls of the Tresa, about one and a half miles southeast of Luvino. The head of this delta is about 100 feet above lake Maggiore and its front, rather illy defined, about 80 feet. It is composed of a rather fine grade of gravel, and largely also of sand, and is thus strongly contrasted with the very coarse materials of the torrent deltas.

Below the main terrace, about 45 feet above the lake, is another smaller, less conspicuous bench. Considering the character of the Tresa and its relatively scanty sources of detrital supply, it seems probable that the heavy upper terrace at Creva is associated with a glacial river of larger volume than the present Tresa and acting when the glacier was still present in the northern half of the Maggiore basin. The lower terrace was probably built by the Tresa at normal volume mainly out of materials excavated from the upper deposit.

Three miles north on the east shore is Maccagno. Here is a torrent delta in typical development. The torrent issues now through a narrow ravine cut in the south part of the old delta. The main part of the village is built on the larger remnant north of the stream. The business and more compact residence portion is on the outer, gentler sloping part of the old delta, while the church and many dwelling-houses are higher up toward the head of the cone. The composition shown in some parts of the bluff front and in banks of the ravine are like those described above as being typical. A cross-section from the ravine lakeward shows a typical delta form with detrital cone superimposed and indicates a lake surface at time of construction 40 to 45 feet above the present water.

Across the lake at Cannobio there is another good example of old delta, but in a more eroded, fragmentary state. The torrent passes out through a deep cut in the north side. The village is built on the old delta surface, the same as at Maccagno. The general level in the business part of the town is gently sloping toward the lake and 60 to 70 feet above it. The outer edge of the gentler slope is 50 to 55 feet above the lake. This is probably not far from the old lake level, which in this case is not well shown. In the valley west of Cannobio, on the north side of the stream, there is a heavy terrace with large boulders. The body of the terrace is composed of till, and the stream now flows in a ravine around its south side. Along the stream, but somewhat below the main terrace, are fragments of narrow, secondary terraces cut in the till. The main terrace appeared to belong to the time of the higher old lake level. The secondary terraces were probably made while the stream was cutting down to its present level.

The projecting part of the delta of the Maggia between Ascona and Locarno is low and broad and flat, and is composed of gravel and sand and silt. This is not an old higher level delta, but has been made since the lake came to its present level. The Maggia and its large tributary, the Merlezzo, are mountain torrents, but for several miles in their lower courses their rate of descent is moderate, so that they do not carry much coarse detritus to the delta. The lake is shallower here than farther south, and the present delta has been built out mainly in a horizontal direction, so as to reach half way across the lake. The general situation makes it evident that if the lake formerly stood, say, 50 or 60 feet higher than now, the delta would have been of the same character—mainly of the finer sediments. East of Ascona, where the delta laps around a projecting ridge, it has the appearance of a sharply cut terrace 40 feet above the lake, but is not in fact of that nature. A mile or more north of Ascona and west of the main road a considerable flat area of fine deposits suggests an old delta, but nothing more definite was seen.

At Locarno and eastward there are many small torrent cones. The village itself is built on a number of these, which blend together at their sides, but they are much eroded and do not seem to show distinct evidence of the place of the former lake surface. Where their slope is least rapid their lower edges are 60 to 80 feet above the lake, but this slope is relatively steep. A well formed delta of a larger torrent is at Gordola, about 3 miles east of Locarno, which seems to show the old lake was 60 to 65 feet above the present. The Morobbia has built a cone or delta of considerable size below Guibiasco, but this was seen only from the train.

The larger rivers—the Ticino above lake Maggiore and the Toce west of Pallanza—were disappointing. In the brief examinations which I was able to make I found no clear evidence of a higher lake level. Their later delta deposits and the cones of the torrents which empty into their valleys appear to have overwhelmed any older deltas which may have been built.

The phenomena below Pallanza led me to believe that, besides being tilted in post-Glacial time, lake Maggiore has cut down its barrier nearly 20 feet. If this be true, then the old lake surface now rises from nearly 20 feet above the present lake at Cesto Calende to between 55 and 65 feet at its north end, near Locarno—that is, the old surface rises 35 to 45 feet in 37 miles. But if the altitudes found near Intra are correct, there appears to be a local upbending of 10 or 15 feet in that vicinity.

This chapter of the history of lake Maggiore is worthy of much more careful and detailed study than I was able to give it in one week. Though I examined most of the places on foot—a few while driving—the intervening stretches along the lake shore were not examined. The most valuable evidences that could be found are those of wave action, of which, however, I found none that were certain. A more detailed study might be expected to discover some evidence of this kind. Evidence exclusively from deltas like those here described does not yield a basis for accurate determination of the old water surface. The best conclusions they afford are only approximations.

LAKE COMO

In two days spent on lake Como I found that the delta at Cernobbio, 2 miles north of the village of Como, stands very low with reference to the present lake. It seems to show a permanent, unchanged relation to the lake level. Steep cones at Argegno and Campo show a slight falling away of the lake—less than 10 feet. At Menaggio the old delta is well developed and indicates a former lake level 12 to 15 feet above the present. Another, equally fine, at Bellano, on the east shore, shows about the same height. A delta at Dervio shows the old lake level at about 20 feet. Three fine specimens of torrent delta-cones occur at Dongo, Gravedona, and Domaso. They are so close together that they are connected by narrow terraces. The old lake level here is about 25 feet above the water. I did not go farther north, but at the same rate of rise the old level at the extreme north end would be about 30 feet, or perhaps a little more. The old lake level in lake Como therefore rises 30 to 35 feet in 30 miles.

Lake Garda

The studies here, as on lake Como, were less detailed than on lake Maggiore, but some of the evidences found are much more satisfactory. The evidence from deltas on this lake is relatively poor, but in its southern expanded part there is a faint, but sharply cut wave-made beach rising toward the north.

The south end of lake Garda expands in bulbous form to a width of 10 miles, and it lies outside of the mountains in the lap of the great moraine. I saw only the west shore of the expanded part. At Maderno there is a well developed delta which shows evidence of the old lake level at about 10 feet. There are faint evidences of wave action from here southwest to Salo at about the same level. On rounding the point east of Salo one obtains a good view of the shoreline from the steamer.

It is here 7 or 8 feet above the lake, and its gradual descent southward is easily noted. Its bench is 10 to 50 feet wide when cut in drift slopes, and the cliff at its back is not over 5 or 6 feet high, and usually lower. It is faint compared with beaches of our American Great Lakes region, and is unlike our fainter beaches in that it is a sharply cut bench wherever I saw it. Our fainter beaches are seldom cut, but generally take the form of a low, more or less broken ridge of sand or fine gravel.

The cut bench is well shown on a small island, Isola di San Biagio, where the bench is cut all around, leaving a higher central part like the crown of a hat. It is well formed also on the Sermione peninsula, but on the rocks of the outer point it is scarcely distinguishable. It de-with clines apparent regularity to within a foot or two of the water at Desenzano, where it is not easily distinguished from the present beach.

The west side of lake Garda, north of Maderno, is mostly precipitous and the streams are small, affording poor opportunity for deltas. On the east side at Ascenza and Malcesine there are faint marks of the old lake level at 18 to 20 feet. At the north end of the lake, between Riva and Arco, there is a tangle of torrent deltas built in by streams from several directions. No definite evidence of the old lake level was observed here, but assuming its plane to be produced from the south it would be somewhere between 25 and 30 feet above the present lake, agreeing well with the level of the delta deposits back of Riva. Thus in 30 miles the old surface of lake Garda rises 25 or 30 feet.

Lake Lugano

This lake is much smaller than the other three described. Its length in a north and south direction is about 9 miles, but its outlet is nearly midway of this distance. At the ends of its two south arms, at Capolago and Porto Ceresio, the shallows grown with reeds seem to suggest a backing up of the water. The delta fronts at Lugano and Porlezza stand 3 or 4 feet above the water. Nothing more definite was found.

A more promising subject, and the only remaining promising one in Italy for studies of this kind, is lake Iseo, but this was not visited.

Lake Geneva

My observations on lake Geneva were fewer than on the Italian lakes, but, so far as they go, seem to indicate a similar direction of deformation, though less in amount. At the time of my visit I was not acquainted with Forel's great work, and so, unfortunately, did not profit by his studies. Forel mentions two principal sets of terraces, one at about 10 meters altitude and the other at about 30 meters,* with a few scattered ones at higher levels. I saw some of these near Vevay, Lausanne, and Thonon. I did not observe wave-made features in connection with them, and so regarded them as products of ice-border drainage rather than true deltas made in the margin of open water. The breadth of lake Geneva in its broader part seems, by comparison with the broader part of lake Garda, to justify the expectation of a recognizable wave-made shoreline, provided the lake stood long enough at one level.

Besides the deltas described by Forel, I found near Lausanne a feature which appeared to be a true old shoreline in the form of a sandy bench 12 to 14 feet above the lake. There appeared to be a faint wave-cut terrace also at Evian and Thonon on the south shore, but at these places only 7 or 8 feet above the water. Faint marks supposed to belong to the same stage of the lake were seen near Nyon and Rolle on the west shore. If these features are of the character supposed, they seem to show an old lake surface rising northward 12 to 14 feet in about 20 miles. Lake Geneva, like the lakes studied in Italy, has its outlet to the south, though its greatest extent in a north and south direction is only 20 miles. Forel's observations suggest no deformation, though the fragments above 30 meters altitude were said to be at discordant heights. A slight differential tilt like that here recorded would be hard to determine in so short a distance as 20 miles by the study of old delta deposits. So small a factor might easily have been overlooked.

Lake Lucerne

The remaining larger Swiss lakes—Neuchatel, Lucerne, Zurich, and Constance—have their outlets to the north. If they have suffered changes of attitude in the same direction as the Italian lakes and lake Geneva, the change has been equivalent to a depression of their southward parts, and, except at their outlets, their waters must now stand at relatively higher levels than formerly; but this kind of change is not so evident on ordinary examination, and its amount is sometimes hard to determine. The only one of these lakes examined was lake Lucerne. No evidence of a higher lake level was found, but, on the other hand, no very certain evidences of submergence were seen. Descriptions of lakes Zurich and Constance indicate the same conditions as for lake Lucerne. It seems probable that these lakes were affected in the same way, and that more detailed study would show southward submergence in all of them.

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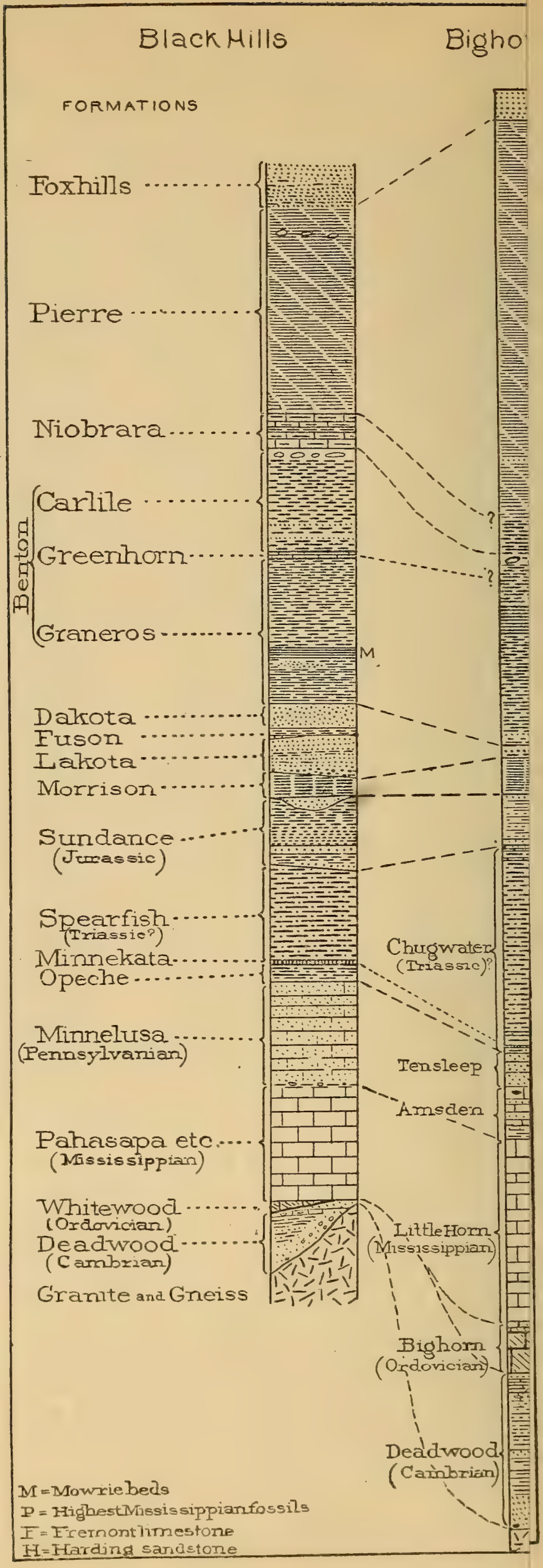
* F. A. Forel: Le Leman, Monographie Limnologique, pp. 175–179.

CONCLUSIONS

The observations here recorded were not sufficiently accurate to determine the exact direction of tilting for the lakes mentioned, but they seem to show a differential elevation having a generally northerly direction.

In another part of his work Forel discusses the origin of lake Geneva. He rejects the glacial theory and regards the basin of the lake as merely a prolongation of the Rhone valley, made when the mountains stood 1,000 meters higher than now. The lake he regards as having originated by a more recent general depression of the mountains to this amount, while the Swiss plain remained relatively unaffected. It would seem natural for one holding Forel's view to explain the Italian lake basins in the same way. If this be done, then the deformation here recorded is due to a resilience of later date than Forel's depression, and would seem to indicate that both depression and resilience were confined mainly to the central region of the Alps. To the present writer glacial agencies seem to have been, perhaps not the sole, but at least the main, cause of all the deeper Alpine lake basins. On this view Forel's recent depression of 1,000 meters would be eliminated, and a cause of tilting must be sought elsewhere.

In "Das Antlitz der Erde" Suess holds that the Adriatic and Black Sea depressions are of recent origin. The shores of the gulf of Genoa suggest a similarly recent depression. A study of the slopes of the Po valley and the floor of the Adriatic sea shows that if the modern delta of the Po, reaching 40 or 50 miles westward from the present mouth of the river, be eliminated, the slope from Pavia to the head of the delta and thence on the Adriatic sea floor out to the bathymetrical line of 100 meters is so nearly uniform as to strongly suggest a subaerial or fluvial origin for the whole of it. If the recent movement of depression supposed by Suess took place, it may have produced as one of its manifestations the observed deformation of the Italian and Swiss lakes. This seems to the writer a more likely cause than that suggested along the lines laid down by Forel, and it agrees with the fact that the Swiss lakes appear to have been tilted in the same general direction as the Italian.


Black Hills
Bigho
FORMATIONS
Foxhills
Pierre
Niobrara
Benton
Carlile
Greenhorn
Graneros
M
Dakota
Fuson
Lakota
Morrison
Sundance (Jurassic)
Spearfish (Triassic?)
Minnekata
Opeche
Minnelusa (Pennsylvanian)
Pahasapa etc. (Mississippian)
Whitewood (Ordovician)
Deadwood (Cambrian)
Granite and Gneiss
Chugwater (Triassic)?
Tensleep
Amsden
Little Horn (Mississippian)
Bighorn (Ordovician)
Deadwood (Cambrian)
?
?
M = Mowrie beds
P = Highest Mississippian fossils
F = Fremont limestone
H = Harding sandstone

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COMPARISON OF THE STRATIGRAPHY OF THE BLACK HILLS, BIGHORN MOUNTAINS, AND ROCKY MOUNTAIN FRONT RANGE*

BY N. H. DARTON

(Presented before the Society December 28, 1903)

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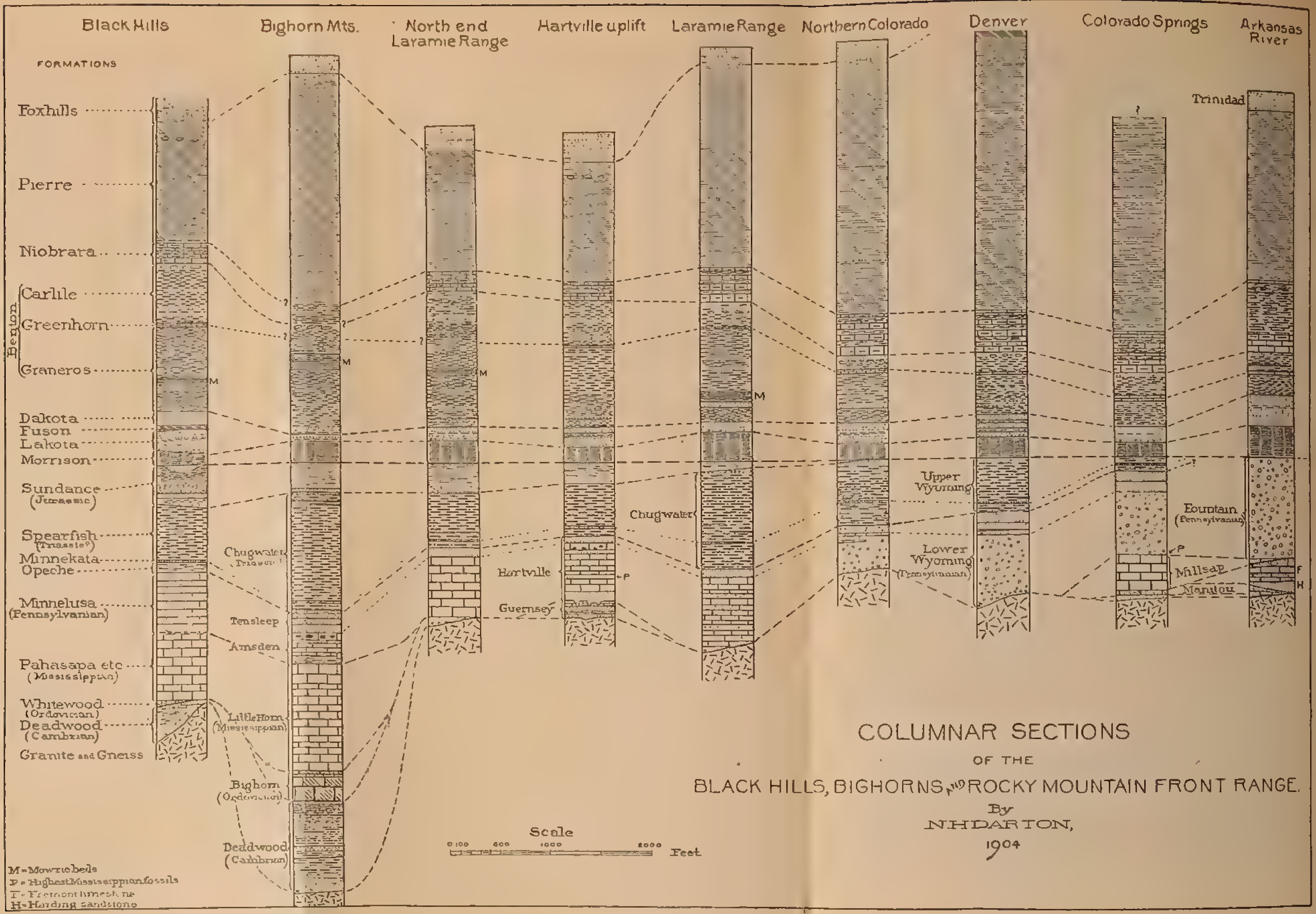
Black Hills
Bighorn Mts.
North end Laramie Range
Hartville uplift
Laramie Range
Northern Colorado
Denver
Colorado Springs
Arkansas River
FORMATIONS
Foxhills
Pierre
Niobrara
Benton
Carlile
Greenhorn
Graneros
Dakota
Fuson
Lakota
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Sundance (Jurassic)
Spearfish (Triassic?)
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Granite and Gneiss
Chugwater (Triassic)
Tensleep
Amsden
Little Horn (Mississippian)
Bighorn (Ordovician)
Deadwood (Cambrian)
Hartville
Guernsey
Chugwater
Upper Wyoming
Lower Wyoming (Pennsylvanian)
Fountain (Pennsylvanian)
Trinidad
Millsap
Manitou
M
P
F
H
?
Scale
0 100 500 1000 2000
Feet
M = Mowrie beds
P = Highest Mississippian fossils
F = Fremont limestone
H = Harding sandstone

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By
N H DARTON,
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INTRODUCTION

For the past six years I have been engaged in detailed studies of the geology of the Black hills and a portion of the Bighorn mountains. Considerable attention has also been given to the sedimentary formations exposed along the Rocky Mountain front range in Wyoming and Colorado. Some of the results of the work in the Black hills have been presented in previous papers and informal accounts have also been given of observations in the Bighorn and Rocky Mountain regions. In the present paper I propose to give a brief presentation of the salient stratigraphic features of the formations in the different areas and point out the regional variations which the formations present.

I think all geologists will be greatly impressed by the wonderful uniformity in most of the formations throughout the region to which this paper relates, a uniformity which indicates widespread unity of conditions in a succession of deposits presenting great variation in character. There are relatively thin sheets of sandstone which underlie many thousand square miles, apparently at constant horizon, limestones and shales of still wider extension, red beds marking a period of very special conditions of wide extent and long duration, and later the great mantle of Tertiary clays and sandstones covering the Great Plains. The interpretation of the geologic history of the great series of formations can only be outlined in a general way with our present information, especially as we have such imperfect knowledge of the significance of many of the rocks and their relations.

BLACK HILLS REGION

LIST OF THE FORMATIONS

There are presented at the surface in the Black Hills uplift a series of formations from middle Cambrian to latest Cretaceous in age, all of the periods being represented in whole or in part, except Silurian, Devonian, and Eocene prior to Oligocene. In the table on page 383 are given the formations of the Black Hills uplift and some of their principal features.

DEADWOOD FORMATION

The outcrop of this formation encircles the Black hills, appearing usually in the base of the great in-facing limestone escarpment. It lies on a relatively smooth surface of Algonkian rocks, although there are many local irregularities of shorelines and beach phenomena. The rocks are mostly sandstones and sandy shales, with frequent occurrences of basal conglomerate. In the southern hills the thickness varies from 4 feet to 50 feet in greater part, and the principal material is a coarse, dark brown, massive sandstone. To the northward the formation gradually thickens, apparently by the addition of higher beds comprising dark gray shales, mostly sandy, and beds of sandstone. In the region about Deadwood, where the formation attains its greatest thickness, of over 400 feet, it comprises about 30 feet of basal conglomerate overlain by 30 feet of coarse, dark brown sandstone; 200 to 400 feet of gray shales, with layers of flaggy limestone, limestone conglomerate, and sandstone; a conspicuous member of hard, massive sandstone 5 to 12 feet thick, and at the top 20 to 45 feet of green shales. The limestone conglomerate is a very characteristic rock, consisting of flat pebbles and flakes of limestone more or less thickly sprinkled with glauconite grains, and is of the intraformational type. A typical exposure of Deadwood sandstone, at Deadwood, South Dakota, is shown in plate 24.

Throughout its course the formation contains fossils of which the following middle Cambrian forms have been reported by C. D. Walcott: Obolus, Hyolithes, Dicellomus, Asaphiscus, Olenoides, Ptychoparia, and Acrotreta.

WHITEWOOD LIMESTONE

This formation is a conspicuous member in the northern Black hills, particularly about Deadwood, where its thickness is 80 feet. Its name was given by T. A. Jaggar, Jr., from typical exposures in Whitewood

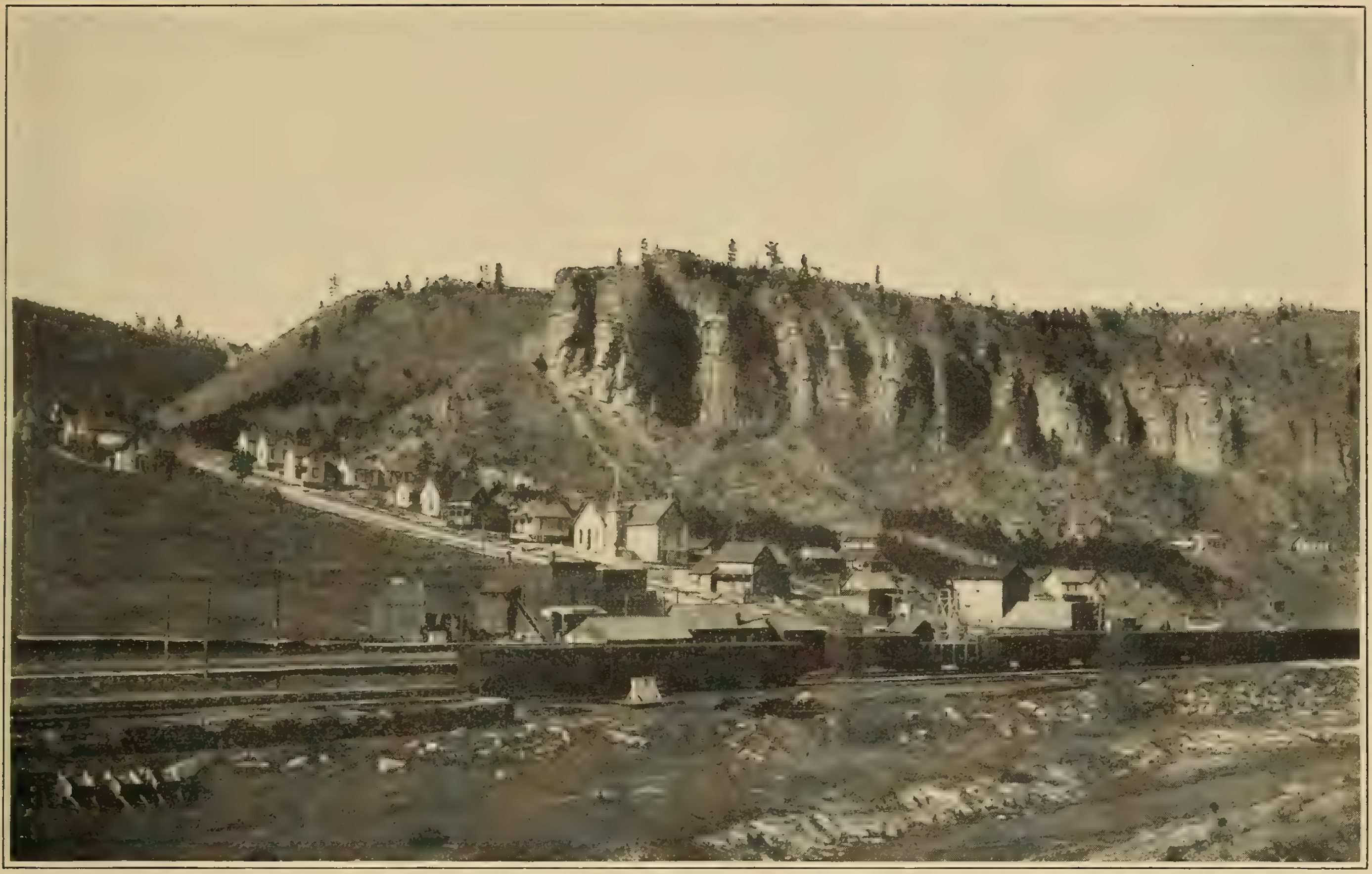

FIGURE 1.—DEADWOOD SANDSTONE

In the lower portion of Deadwood, South Dakota. Looking north

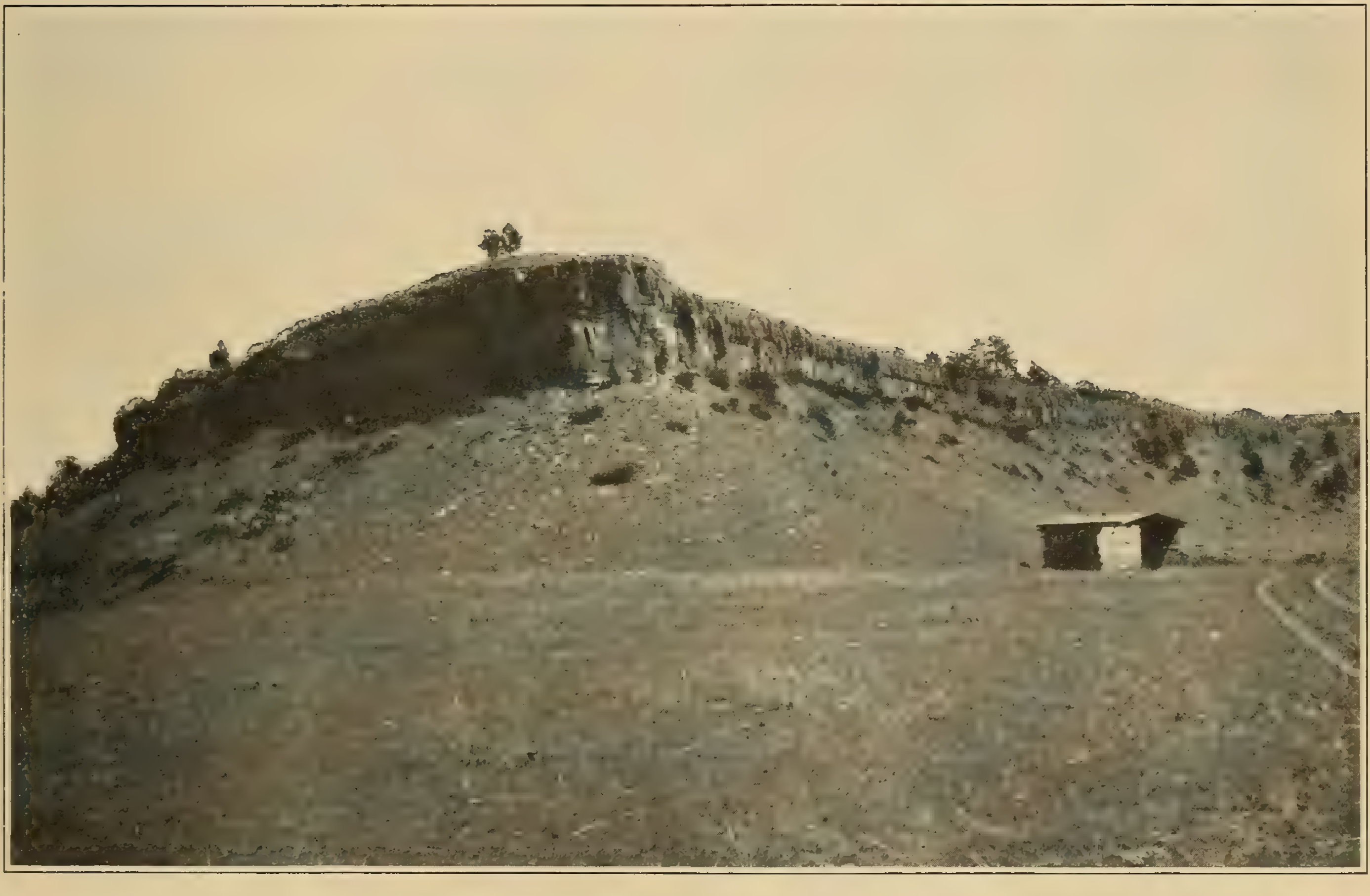

FIGURE 2.—MINNEKAHTA LIMESTONE

In Gillette canyon, southeast of Newcastle, Wyoming. Typical cliff surmounting slope of Opeche red beds

DEADWOOD SANDSTONE AND MINNEKAHTA LIMESTONE

Period.	Formations.		Principal characters.	Average thickness, feet.
Cretaceous	Laramie		Massive sandstone and shale	2,500
	Fox Hills		Sandstone and shale	250–500
	Pierre shale		Dark gray shale	1,200
	Niobrara		Chalk and calcareous shale	100–225
	Benton group	Carlile	Gray shales, with thin sandstones, limestones, and concretionary layers.	500–750
		Greenhorn limestone	Impure slabby limestone	50
		Graneros shale	Dark shale, with local lenses of massive sandstone in its lower part.	900
	Dakota sandstone		Massive buff sandstone	35–150
	Fuson		Very fine grained sandstone and massive shales, white to purple color.	30–100
	Minnewaste limestone		Gray limestone	0– 30
	Lakota		Massive buff sandstone, with some intercalated shale.	100–350
	Morrison		Pale grayish green shale	0–150
Jurassic (?)	Unkpapa sandstone		Massive sandstone—white, purple, red, buff.	0–250
Jurassic	Sundance		Dark drab shales and buff sandstones; massive red sandstone at base.	60–400
Triassic (?)	Spearfish		Red sandy shales with gypsum beds	350–700
Carboniferous (Permian)	Minnekahta limestone		Thin bedded gray limestone	30– 50
	Opeche		Red slabby sandstone and sandy shale	90–130
Carboniferous (Pennsylvanian ?)	Minnelusa		Sandstones, mainly buff and red; in greater part calcareous; some thin limestone beds included.	450–750
Carboniferous (Mississippian)	Pahasapa limestone		Massive gray limestone	250–400
	Englewood limestone		Pink slabby limestone	25– 50
Ordovician	Whitewood limestone		Massive buff limestone	0– 80
Cambrian (Middle)	Deadwood		Red-brown quartzite and sandstone, locally conglomeratic, partly massive, and shale.	4–450
Algonkian			Schists and granites.	

canyon, below the town of Deadwood. It thins out to the southward and disappears in the central Black hills.

The rock is a massive, tough limestone of buff color, with brownish spots or mottlings. It contains large Endoceras, Maclureas, and corals of Ordovician age lying on the Cambrian shales, to which it conforms in attitude, but from which it is separated by a planation unconformity representing later Cambrian time. In part of the area it is overlain by several feet of greenish shales which may possibly be of Devonian age, but no fossils have as yet been found in them.

ENGLEWOOD LIMESTONE

This basal member of the Mississippian division of the Carboniferous extends throughout the Black Hills area. It is a thin bedded, pale pinkish buff limestone, from 25 to 50 feet in thickness. It is abruptly separated from the underlying Deadwood or Whitewood formation, but although there is an intervening unconformity, probably representing all of Silurian and Devonian time, there is no discordance in dip and no evidence of channeling. Above, it merges rapidly into the overlying Pahasapa limestone, in some cases with a few feet of impure buff limestone beds of passage. Fossils usually occur throughout down to the Cambrian or Ordovician contact. The following forms have been reported: Fenestella, Orthothetes, Leptæna, Spirifer, *Chonetes logani*, *Reticularia peculiaris*, *Syringothyris carteri*, and crinoids. It is correlated with the Chouteau or Kinderhook of the Mississippi valley.

The formation was differentiated by T. A. Jaggar, Jr., and named from extensive exposures at Englewood, in the northern Black hills.

PAHASAPA LIMESTONE

This is the prominent "gray limestone" of the high plateaus in the Black Hills uplift. The rock is in massive beds, having a total thickness of from about 250 feet in the southern hills to 400 feet northward, with a maximum amount of 700 feet reported by Jaggar in the vicinity of Spearfish canyon. The character of the rock is relatively uniform, but the upper portion of the formation is somewhat more silicious and flinty.

Fossils occur sparingly throughout the formation, including the *Spirifer rockymontanus*, *Seminula dawsoni* (*Athyris subtilita*), Productus, and Zaphrentis, a fauna which indicates Mississippian (Lower Carboniferous) age.

MINNELUSA FORMATION

The Minnelusa formation consists mainly of thick beds of gray, buff, and reddish sandstones, usually fine grained, most of which, in their unweathered condition, contain a considerable proportion of carbonate of lime. Thin sheets of limestone occur in some districts, and, less frequently, sandy shales of red or gray color. Some layers are cherty. The formation is prominent on the outer slopes of the higher ridges of the encircling rim of the hills. It is thickest on the western side, where it is fully 750 feet, and it thins gradually to the south and east, being about 400 feet thick in the southeastern portion of the uplift.

The formation presents local variations. There is generally a lower member of buff, slabby sandstones often 100 feet in thickness. Next above there are usually more massive sandstones, in part brecciated and often of red color. In the northeastern portion of the area, the Minnelusa beds comprise a thick mass of coffee colored sandstone at the top, reddish buff sandstone with some thin, interbedded limestone layers next below, and the basal member of gray sandstones. On the western side of the Black hills the upper sandstones are light colored, often pure white, the medial member consists of red and buff sandstones and the basal member is gray, calcareous sandstone with reddish shale partings and considerable chert. Sandstone predominates everywhere in the outcrops, but in the borings from the deep well at Cambria, on the west side of the hills, it is found that nearly all of the rocks contain considerable carbonate of lime in their unweathered condition. At the base of the formation there usually occurs a red shaly bed of slight thickness, containing oval, fossiliferous concretions of hard silica, from 6 inches to 2 feet in diameter in greater part.

Very few fossils have been obtained from the Minnelusa formation, and the only determinable ones so far discovered were obtained from upper beds west of Hot Springs, where, among some indistinct casts *Productus semireticulatus* and *Seminula dawsonii* (*Athyris subtilita*) were recognized with a fair degree of certainty. It is on the basis of this not very conclusive evidence that the upper part of the formation, at least, is referred to the Pennsylvanian division of the Carboniferous, a determination which is somewhat strengthened by the similarity of the deposits to other formations in the Northwest which yield Upper Carboniferous fossils. There are some reasons, which will be presented later, for believing that the lower beds may represent the Mississippian.

OPECHE FORMATION

In this formation the first of the Red beds makes its appearance in the Black Hills region. The materials are soft, red sandstones, mainly thin bedded and containing variable amounts of clay admixture, having a thickness varying from 120 feet in the southeastern part of the hills to about half that amount to the northwestward. The basal beds of the formation are usually red sandstones, the beds varying in thickness from 4 to 13 inches. Gypsum occurs at a few points in beds which are neither thick nor extensive.

The age of the formation has not been definitely determined, for so far it has yielded no fossils. From the fact that the overlying Minnekahta limestone is of Permian age, and the deposition of gypsiferous Red beds in other regions began in Permian time, the formation is provisionally assigned to that division.

MINNEKAHTA LIMESTONE

Overlying the Opeche Red beds there is a limestone persistent over a wide area in the Northwest, which I have designated the Minnekahta limestone. Though thin, averaging less than 50 feet in thickness, it is hard, flexible, and, by the easy erosion of the Red beds in which it is inclosed, outcrops in long slopes and prominent ridges.

The rock is uniform in character throughout, being a thin bedded, light colored limestone, containing magnesia and more or less clay. Its thin bedding is a characteristic feature, although the thin layers are so cemented together that the outcropping ledges present a massive appearance, as shown in plate 24. On weathering, it breaks into slabs usually 2 to 3 inches in thickness. On the western side of the hills its coloring is slightly darker, varying from a dove color to lead gray, and some of the beds present a semi-nodular structure. An increased admixture of clay is also observed in some layers. The general appearance of the formation is always slightly pinkish, with a tinge of purple, from which fact the old term "purple limestone" originated.

The limestone contains fossils at a number of localities, but the forms are not well preserved and not altogether decisive as to the age of the deposits. At a locality 15 miles west-northwest of Hot Springs there were observed a *Bakewellia* and *Edmundia* similar to those observed in the Kansas Permian, and from this evidence the limestone is assigned to the Permian. Near Sturgis similar fossils occur.

SPEARFISH FORMATION

The designation Spearfish formation has been applied to the main body of gypsiferous Red beds which outcrop in a broad zone encircling the Black Hills uplift. This formation consists of from 350 to 700 feet of red, sandy clays, with intercalated beds of gypsum which sometimes are 30 feet thick. The bright red color of the shales and the snowy white of the gypsum are striking features of the formation. Were it not for the gypsum the formation would present no noticeable features of stratigraphy, as the sedimentary material is almost entirely a red shale con-

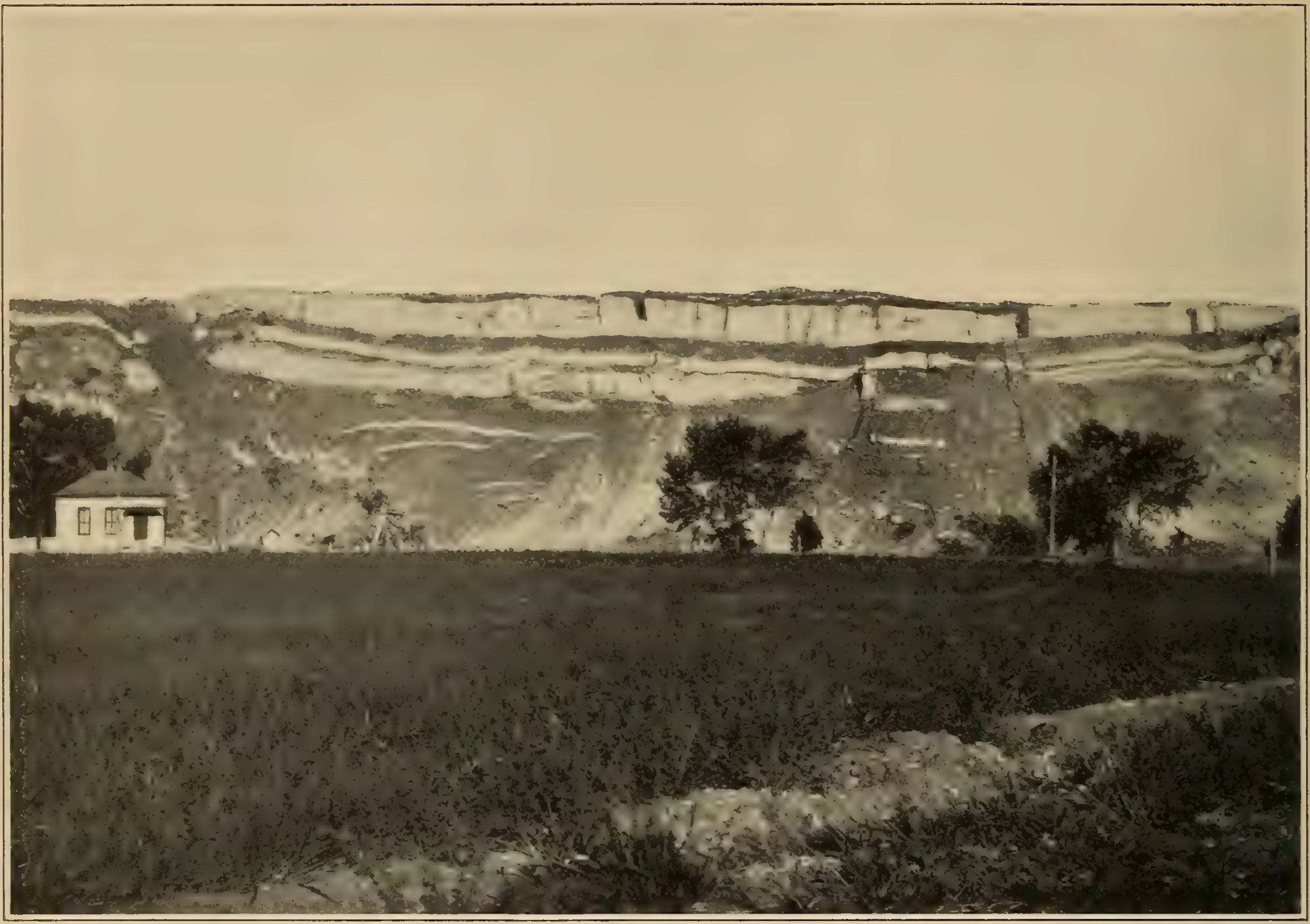

Figure 1.—Gypsum Deposits in Spearfish Red Beds, near Hot Springs, South Dakota

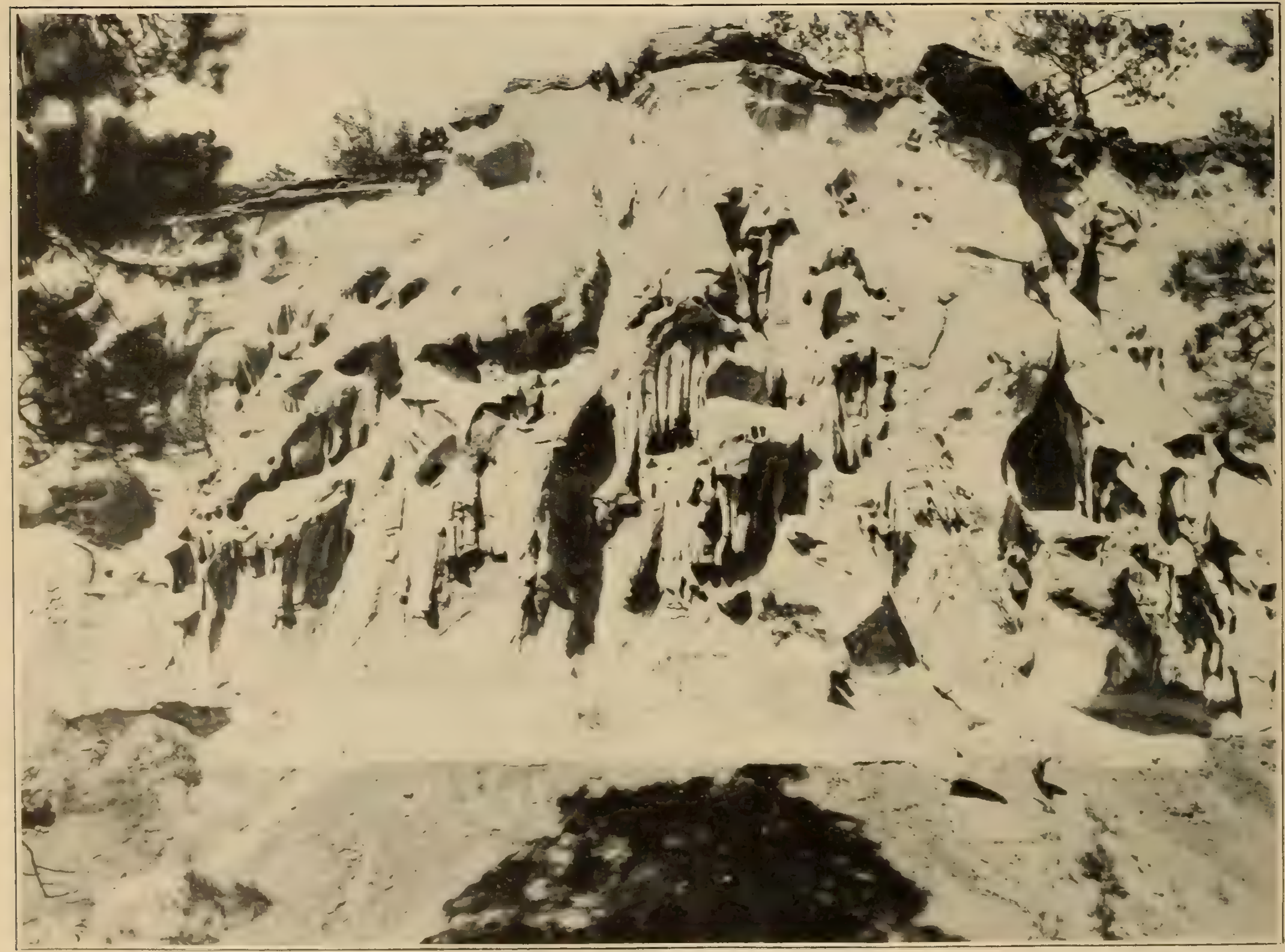

Figure 2.—Massive Sandstone at Base of Sundance Formation

Lying unconformably on red shales of Spearfish formation

SPEARFISH RED BEDS AND OVERLYING MASSIVE SANDSTONE taining varying amounts of fine sand admixture. It is generally thin bedded. The gypsum occurs in beds at various horizons, some of the larger beds extending continuously over wide areas. There is also throughout the formation more or less secondary deposition of gypsum in small veins.

The thickness of the Spearfish formation can seldom be determined with accuracy, owing to the softness of the material and the predominance of low, variable dips which are difficult to measure. Along the east side of the Black hills the formation appears to have a thickness of from 350 to 400 feet, but the amount increases to the northward to 492 feet in the well at Cambria, 695 feet in a well at Sturgis, and at least 650 feet in a deep boring at Aladdin. To the southeastward the principal bed of gypsum generally varies from 5 to 15 feet, increasing southward in the vicinity of Hot Springs to the maximum development, in which the principal beds have a thickness of 33½ feet, with a 10-foot parting of red shale between. These beds are shown in plate 25. Along the west side of the uplift there is usually a bed of gypsum at a horizon about 150 feet above the base of the formation, and east of Newcastle for some distance there is a 25-foot bed of gypsum at the top of the formation shown in figure 1, plate 26, several thin beds in its center, and at its base a local thin bed of gypsum lying directly on the Minnekahta limestone. Throughout the Black hills the formation is distinctly separated from the underlying Minnekahta limestone by a very abrupt change of material, and from the overlying marine Jurassic deposits and by a well marked erosional unconformity.

No fossils have been found in the Spearfish formation of the Black hills excepting a few fragments that were indeterminable. Its age has been supposed to be Triassic. While this may be correct, there are evidences in other regions that it may possibly belong to a somewhat earlier period, in which case the Triassic time, as well as earlier Jurassic, is represented by the unconformity at its top.

SUNDANCE FORMATION

This name has been given to the marine Jurassic sediments of the Black Hills region from the town in the northern portion of the uplift. The rocks are shales and sandstones in a series, some members of which vary locally. Over a wide area the succession consists of a lower member of dark gray shales, averaging 50 feet thick; a prominent ledge of fine grained sandstones of pale buff tint; an intermediate member of sandy shales and sandstones of reddish color, and at the top about 150 feet of dark green shale, including thin layers of very fossiliferous limestone. A characteristic exposure is shown in plate 26, in which the lower sandstone appears in a prominent cliff. Fossils occur also in the sandstone and all are of later Jurassic age. At the base of the formation there is often a massive red or buff sandstone occurring in extended lenses, and frequently attaining a thickness of 25 feet, lying unconformably on Spearfish red shales, as shown in plate 25, figure 2.

UNKPAPA SANDSTONE

This formation extends all along the eastern side of the uplift, but has its greatest development at the extreme southeast. The rock is a sandstone, characterized by its fine grain and very massive bedding, and varies from white to purple and buff in color. It reaches its greatest thickness of 225 feet south of Hot Springs, but is thin northward, except in the vicinity of Rapid City, where it thickens to 150 feet. It appears to be conformable to the underlying Sundance formation, but begins abruptly without transition beds.

The formation has not yielded fossils. It is a product of beach and shallow water deposition, either at the close of the Jurassic or the beginning of early Cretaceous time. It is provisionally classed in the former.

On the western and northwestern side of the Black hills a thin bed of buff sandstone occurs at the top of the Sundance formation, which may represent the western extension of this formation. In this case it may possibly constitute a bed of passage from the Sundance to the Morrison formation.

MORRISON SHALES

This formation has been known as the "Atlantosaurus beds" and Beulah shale. It is extensively developed in the Black hills, excepting to the southeast, where it is absent, and its place apparently is represented by an unconformity by erosion on the surface of the Unkpapa sandstone.

The Morrison deposits are mainly massive shale or "joint clay," somewhat more fissile and darker to the east than to the north and west. The predominant color is a light greenish gray merging into chocolate and maroon tints. Thin beds of fine grained, white or light gray sandstone are included, and some thin local layers of impure limestone. A few fresh-water shells have been observed, and an almost general occurrence of saurian bones, believed to be of earliest Cretaceous age, although some paleontologists regard them as late Jurassic. Where the formation lies on the Unkpapa sandstone and Sundance shales, there is apparent conformity and rapid change from one material to the other, but if the Unkpapa sandstone is not represented in the area in which

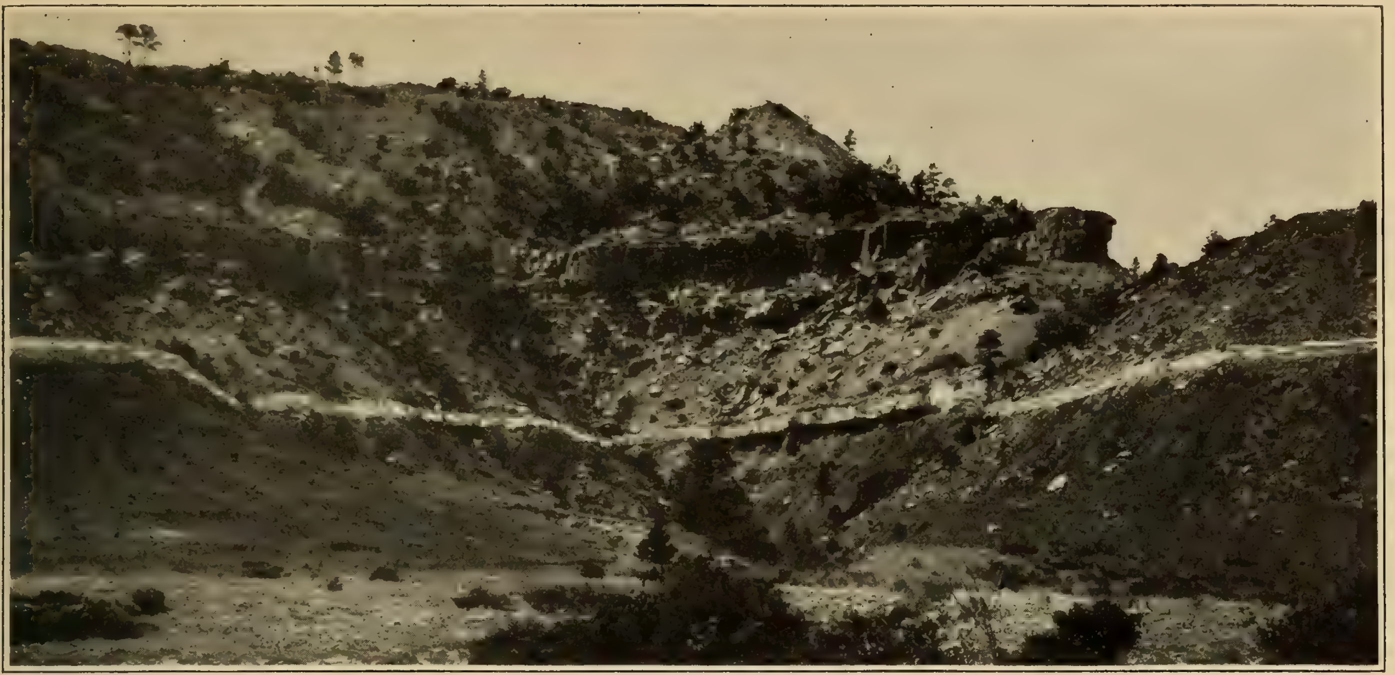

Figure 1.—Sundance and Associated Formations on east Side of Stockade, Beaver Valley, Wyoming

A. Gypsum at top of Spearfish formation

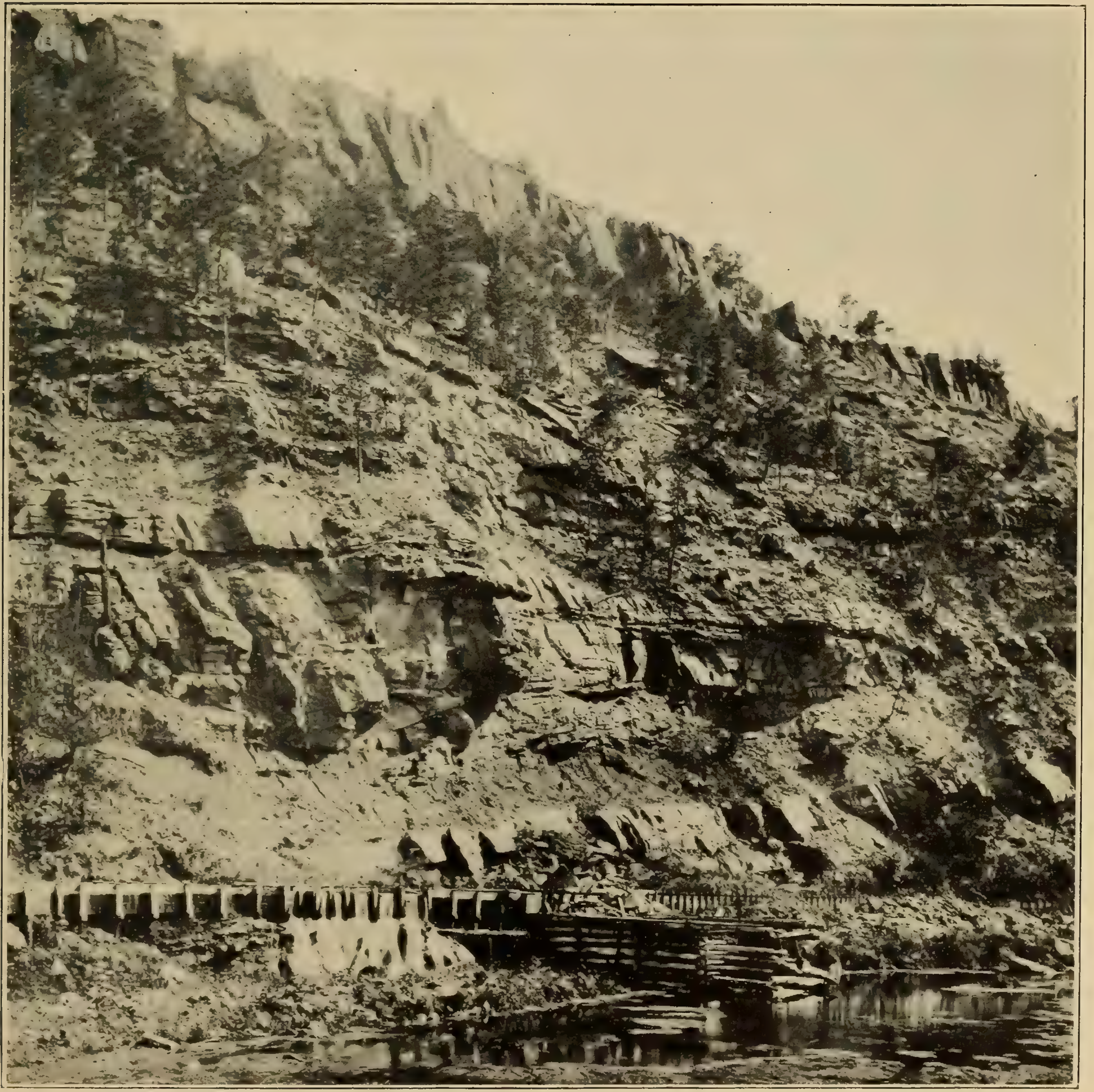

Figure 2.—Typical Exposure of Lakota Sandstone in Fall River Canyon, South Dakota

SUNDANCE AND ASSOCIATED FORMATIONS

the Morrison shales appear to lie on the Sundance shales, there must be an intervening unconformity representing Unkpapa time.

LAKOTA SANDSTONE

This sandstone gives rise to the crest and upper slopes of the hogback ranges forming the outer encircling rim in the Black hills. The rocks are mostly hard, coarse grained, cross bedded, and massive, with partings of shale of no great thickness. Locally there are beds of coal in the lower portion of the formation, which, about Cambria and on Hay creek, are mined to some extent. The thickness is usually from 200 to 300 feet, excepting far to the northward, where the amount diminishes to 100 feet or less. The Lakota sandstone lies unconformably on the Morrison shales to the north and west and on the Unkpapa sandstone, where the Morrison is absent to the southeast, but without discordance of dip. The amount of unconformity between the Lakota and Morrison is probably very slight, or no more than is usually exhibited where coarse sands have been deposited on clays. The unconformity with the Unkpapa is more profound and contact usually presents considerable channeling.

Excepting petrified wood, which is abundant, fossils are rarely found in the Lakota formation. Near Buffalo gap there were found some bones of a stegasaurus of advanced type, such as might be expected in the early Cretaceous time. Plants of Lower Cretaceous age appear east of Hot Springs and in the Hay Creek region,* and pine needles are abundant in some of the coaly layers. Numerous cycads have been found, notably in the southern and eastern parts of the uplift, and recently Professor O'Harra has observed one far to the north. This geologist also discovered 3 miles north of Piedmont the following fossils, which were determined by Dr T. A. Stanton: A new isopod crustacean, probably of the family Ægidæ; an Estheria, fish scale of a gar, Lepidosteus, and a crocodile tooth—all fresh-water forms.

MINNEWASTE LIMESTONE

This formation overlies the Lakota sandstone in the southern portion of the uplift, with a maximum thickness of only 25 feet. It is a nearly pure, light gray limestone and was not found to contain fossils. It is, however, of Lower Cretaceous age, for the next succeeding formation contains distinctive fossil plants. One of its most extensive exposures is at the falls of Cheyenne river, which are due to a ledge of this limestone.

FUSON FORMATION

This is a thin sheet of clays lying between the Lakota and Dakota sandstones and was originally comprised in the "Dakota sandstone" group. It has been found to extend throughout the Black Hills uplift and into other regions. Its thickness averages about 50 feet, but varies considerably and is greatest in the northern and southern extremities of the uplift. The material consists mostly of a mixture of clay and fine sand usually massively bedded. Some beds of sandstone are included, and there are extensive deposits of nearly pure shale. The predominant color is white or gray, but buff, purple, and maroon tints are often conspicuous. One of the most characteristic exposures in the southern hills is at the falls of Cheyenne river, where the following beds are shown:

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*The Lower Cretaceous of the Black Hills, by L. F. Ward, U. S. Geological Survey. Nineteenth Annual Report, pt. ii pp. 521–946.

	Feet
Dakota sandstone	
Dark sandy shale	4
Soft gray slabby sandstone, plants	6
Compact white mudstone	8
Dark green clay	1
Dark gray compact mudstone	25
Very compact white mudstone	2½
Gray mudstone	6
Harder white mudstone	9
Purplish shale	1
White fine grained sandstone	5–12
Purple shale	6– 8
Light buff massive sandstone	25
Dark buff coarser sandstone, much honeycombed by weathering	25

In Fuson canyon, on the east side of the hills, a typical locality, the uppermost bed is a moderately hard sandstone underlain by 10 feet of purplish gray shale. then 10 feet of massive white shale, and at the base 20 feet of bright purple shale. Farther north the formation varies from 50 feet of white massive shale, on as Dry creek, to about the same amount of buff and purple shale overlain by several feet of alternations of buff shale and thin sandstone. Near Rapid the thickness is 100 feet, and in the northern hills it varies from 60 to 100 feet. In this region, in the vicinity of Hay creek, the formation has yielded large numbers of fossil plants of Lower Cretaceous age, described by L. F. Ward.* They were collected by W. P. Jenny from "the upper part of division number 2."

DAKOTA SANDSTONE

This formation is the uppermost member of the series, formerly designated "Dakota sandstone," in the Black Hills region. Being rarely over 100 feet thick, it constitutes only a small part of the mass of the hogback range; but it is a conspicuous formation, because the foothills which usually mark its outcrop rise steeply out of the lowlands of shale. It generally consists of brown sandstone, hard and massive below, as shown in figure 2, plate 26, but thinner bedded above. It presents little variation in thickness and character. The rock is mostly coarse grained more or less cross-bedded, and usually contains more oxide of iron than the Lakota sandstone. It contains fossil plants which are impressions of characteristic dicotyledonous leaves of the Dakota or Upper Cretaceous flora.

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* Loc. cit., p. 946.

GRANEROS FORMATION

This formation, which is the lowest member of the Benton group, outcrops in the broad band of lowlands encircling the hogback range of the Black hills. It has an average thickness of about 900 feet, consisting mostly of fissile black shales, though in some districts there is included a bed of sandstone from 1 to 30 feet thick, at a horizon from 200 to 300 feet above the base of the formation. This sandstone is noticeable in the vicinity of Newcastle where it contains some petroleum, near Rapid and Hermosa, on the east side of the hills, and at a few points in the northern foothills. At a horizon a short distance above this sandstone horizon there occurs a very distinctive series of hard, sandy shales, from 50 to 300 feet thick, which extends entirely around the uplift. These shales are characterized by weathering to a dull silver gray color, by containing large numbers of fish scales and by usually giving rise to a low but distinctive ridge bearing a stunted growth of pines. They attain great prominence near the Belle Fourche, at the northern end of the uplift, where, according to observations by Professor O'Harra, their thickness is 300 feet and their top lies 200 feet below the summit of the Graneros formation. At Newcastle, in the central-western side of the uplift, this series is thin and lies about 700 feet below the top or just above the sandstone lens. The overlying deposits are dark gray shales throughout the region.

GREENHORN LIMESTONE

This is an impure limestone lying near the middle of the Benton group, which gives rise to a low but distinct escarpment extending around the Black hills. The bed averages about 50 feet thick and is everywhere characterized by large numbers of impressions of *Inoceramus labiatus*, a fossil of infrequent occurrence in the adjoining formations. It appears to gain hardness on weathering, breaking out into hard, thin, pale buff slabs, generally covered with impressions of the distinctive fossil. At its base it is usually distinctly separated from the dark shales of the Graneros formation, but it grades upward into the overlying formation through 6 or 8 feet of passage beds. In some portions of the northern hills it is less distinct and less fossiliferous than to the southward. About Edgemont and east of Hot Springs it is a prominent feature. A typical exposure showing the alternation of thin-bedded limestones and the abrupt change between Graneros and Greenhorn deposits is shown in figure 2, plate 27.

CARLILE FORMATION

This upper member of the Benton group consists mainly of shales, with occasional thin beds of sandstone, and at the top contains numerous oval concretions. The thickness varies from 500 to slightly over 700 feet, the larger amount being along the west side of the uplift. The following section of Carlile formation, 3 miles west of Newcastle, is typical:

	Feet
Niobrara chalk	
Dark shales, with light colored concretions	130
Dark shales	200
Calcareous concretions	3
Sandy shales, with thin sandstones	170
Brown sandstone	4
Greenhorn limestone	

Typical Benton fossils occur at intervals in the Carlile formation, mainly in thin beds of limestone or in the concretions of the upper series. The concretions of the upper series of the formation are especially characterized by the occurrence of the *Prionotropis woolgari.*

NIOBRARA FORMATION

The calcareous deposits of this formation completely encircle the Black hills, but in a few districts to the northwestward they are not as distinctive as in other portions of the uplift. The typical material is a light gray, soft shaly limestone or impure chalk, containing greater or less admixture of clay and fine sand. Its weathered outcrops have a bright yellow color, which usually renders them conspicuous, although, owing to the softness of the materials, they rarely give rise to notable ridges. The thickness averages about 200 feet, except to the northwest, which is about 100 feet. Thin layers of hard limestone are often included, consisting of an aggregation of shells of *Ostrea congesta*, a fossil distinctive of the formation when it occurs in colonies.

PIERRE SHALE

The Great plains area adjoining the Black hills is occupied mainly by the Pierre shale, a formation consisting of a thick uniform mass of dark

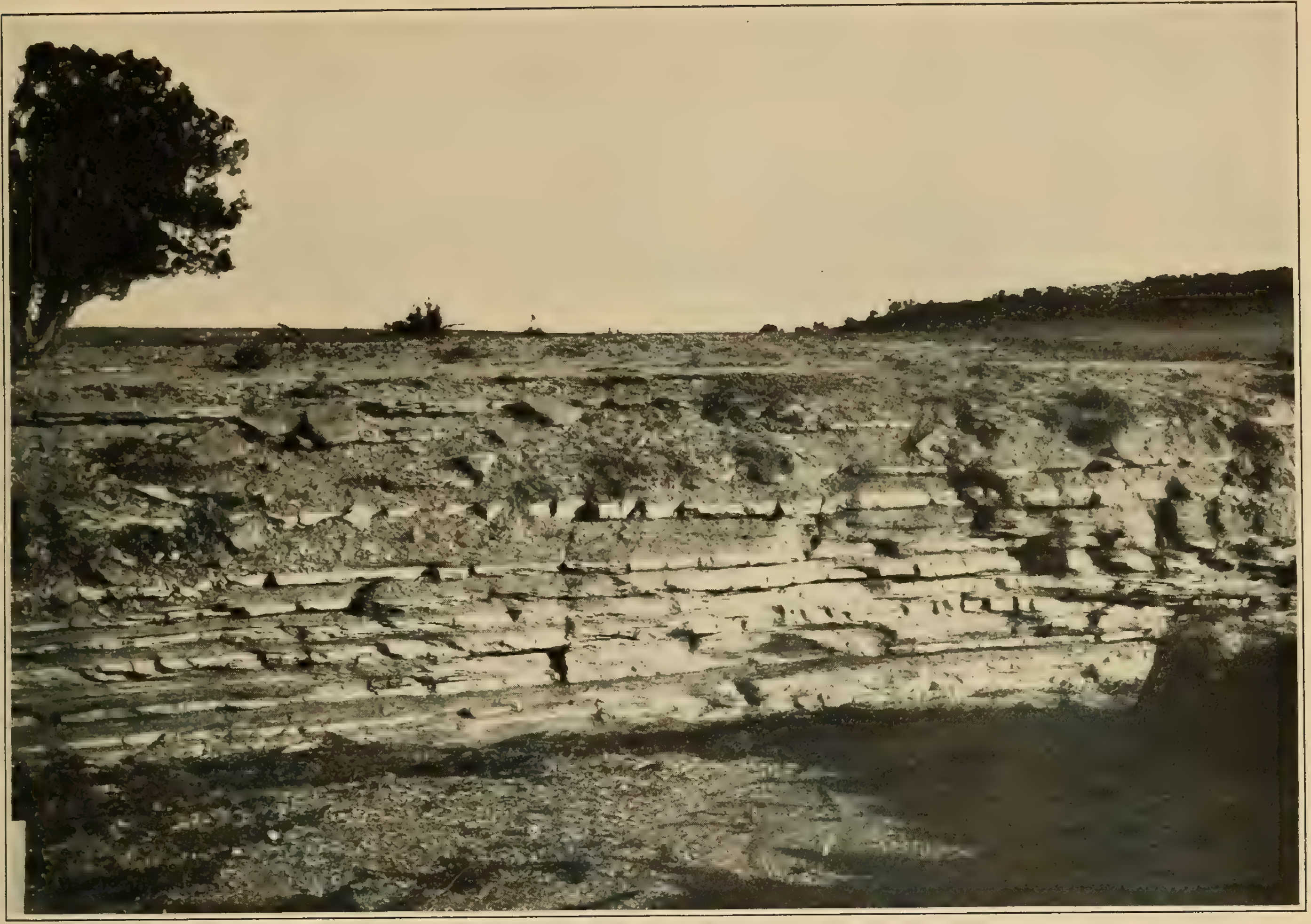

Figure 1.—Greenhorn Limestone east of Pueblo, Colorado (Photographed by G. K. Gilbert)

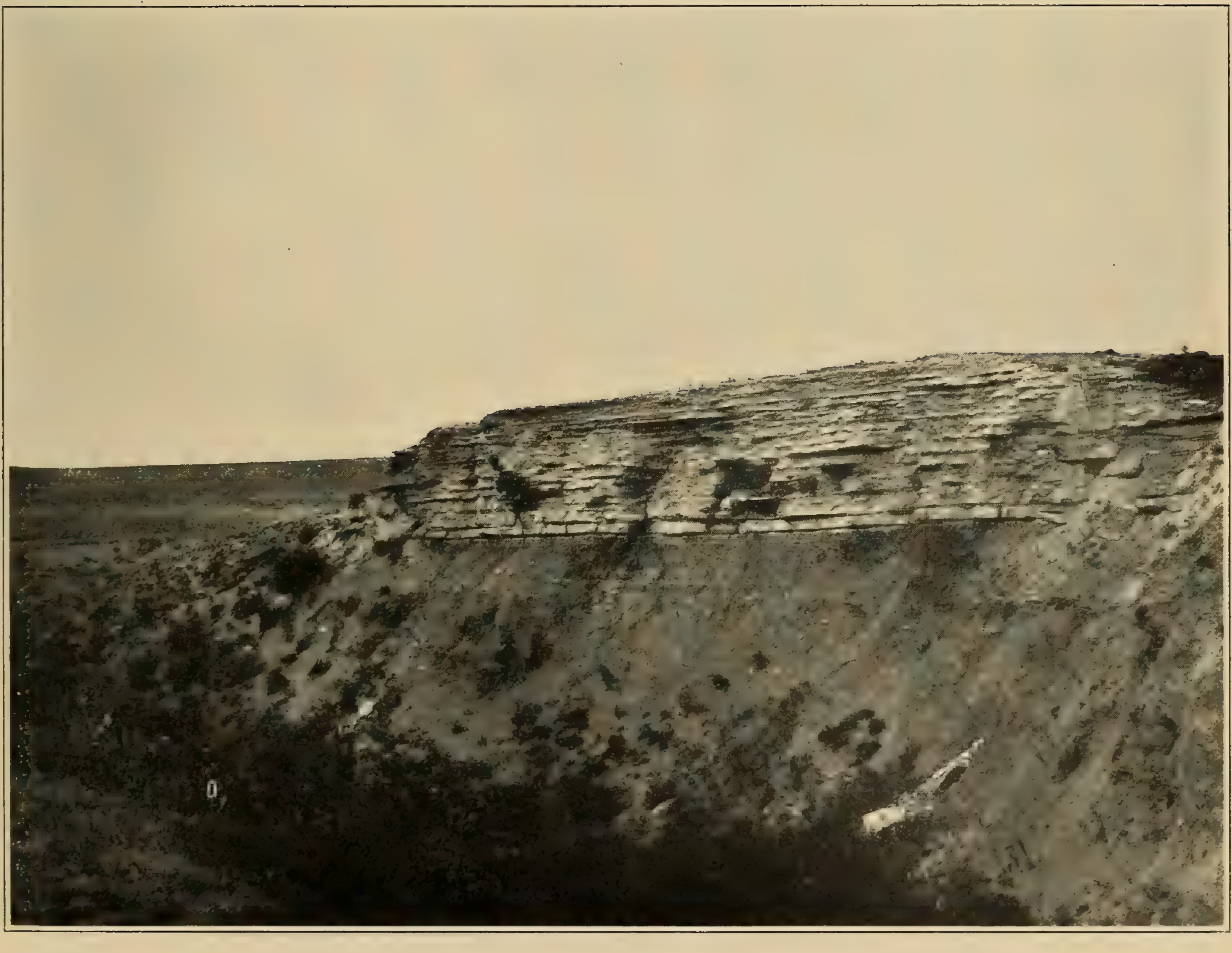

Figure 2.—Greenhorn Limestone south of Edgemont, South Dakota

TYPICAL ALTERATION OF THIN LIMESTONE BEDS AND SHALE

colored shale weathering light brown. Its thickness is about 1,200 feet, so far as can be ascertained, but, owing to the general low dips, the amount rarely can be determined. No details of stratigraphy have been established in the formation, excepting that at a horizon of about 1,000 feet above its base there frequently occur lenses of limestone containing numerous shells of *Lucina occidentalis.* These lenses are often 15 to 20 feet in diameter and 6 to 8 feet thick, and, owing to their hardness, when they are uncovered by erosion they give rise to low conical buttes resembling in form a squat tepee. Accordingly these forms have been designated tepee buttes, a term used for similar occurrences in the Pierre shale in southeastern Colorado.

Numerous concretions occur in the Pierre shales at various horizons, which usually contain large numbers of very distinctive fossils, of which the more abundant are the following species: *Baculites compresus, Inoceramus sagensis, Nautilus dekayi, Placenticeras placenta, Heteroceras nebrascensis*, and an occasional *Lucina occidentalis.* The most fossiliferous horizon is in the upper part of the formation. The concretions are generally of small size, of a calcareous nature, and break into small pyramidal fragments, which are more or less scattered all over the Pierre surfaces. At the base of the formation overlying the Niobrara chalk there is always a very distinctive series of black, splintery, fissile shales, containing beds of concretions, which have been included in the Pierre shales, although they have not yet been found to contain distinctive fossils. The thickness of the series is about 150 feet, and it gives rise to a steep slope often rising conspicuously above the lowlands eroded in the Niobrara chalk.

FOX HILLS AND LARAMIE FORMATIONS

To the west and north of the Black hills there are extensive areas of Laramie and overlying formations, separated from the Pierre shale by a narrow band of outcrops of the Fox Hills sandstone. This sandstone develops gradually from beds of passage with typical Fox Hills forms, mainly Veniella, although in some districts Pierre fossils extend upward for some distance into the sandy beds. The thickness of the Fox Hills sandstones is from 250 to about 500 feet. They grade upward into soft massive sandstones alternating with carbonaceous shales containing no marine fossils, but often yielding plants of the Laramie flora. Not far above the sandstones, which are believed to be at the top of the Fox Hills formation, there occur the remains of Ceratopsidæ, which have been described by Hatcher, and these in turn are surmounted by beds which Knowlton has found to contain a typical Fort Union flora. The Ceratops beds have been described by Hatcher* and by Stanton and

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*Am. Jour. Sci., 3d series, vol. 45, pp. 135-144.
Am. Naturalist, vol. 30, pp. 112-120.

Knowlton,* who have shown from the faunal, floral, and stratigraphic evidence that they are of Laramie age.

Bighorn Mountains

GENERAL CHARACTERISTICS OF THE SECTION AND LIST OF FORMATIONS

During the past three seasons many months have been devoted to a study of the stratigraphy of a portion of the eastern side of the Bighorn uplift. Some observations in this district were made several years ago by Mr George H. Eldridge.† The Bighorn section presents much similarity to that of the Black Hills, but with certain differences of detail, as might be expected; the Cambrian and Ordovician and also Graneros are more extensively developed, the Red beds are thicker, the Lakota and Dakota sandstone and Niobrara formations are much less distinct, and the Greenhorn limestone was not recognized. The following is a list of the formations on the east side of the Bighorn mountains in Wyoming:

	Formations.	Principal characters.	Thickness.
			Feet.
Cretaceous	Laramie	Sandstones and shales, with local coal beds; lenses of conglomerate near base.	2,000±
	Fox Hills	Soft buff sandstone	200
	Pierre	Dark gray shales	2,700
	Niobrara	Gray shales	200±
	Benton	Dark shales: sandy shale, with thin rusty sandstone layers at base	1,150
	Cloverly	Gray to purple clay (Fuson)	30
		Coarse sandstone (Lakota)	30
	Morrison	Massive shales and sandstones	150–250
Jurassic	Sundance	Buff sandstones and green shales	300
Triassic (?) or Permian.	Chugwater	Red sandstone and shales with gypsum (Spearfish).	1,200
		Purple to gray limestone (Minnekahta?)	5
		Red shales (Opeche?)	30
Carboniferous	Tensleep	White sandstone	50–200
	Amsden	Red shales, white limestone, and cherty limestone.	300
	Little Horn	Limestones of light color	1,100
Ordovician	Bighorn	Limestone, in greater part very hard and massive.	250
Cambrian	Deadwood	Sandstone, shale, conglomerate, and limestones.	1,000
Algonkian or Archean.	....	Granite.	

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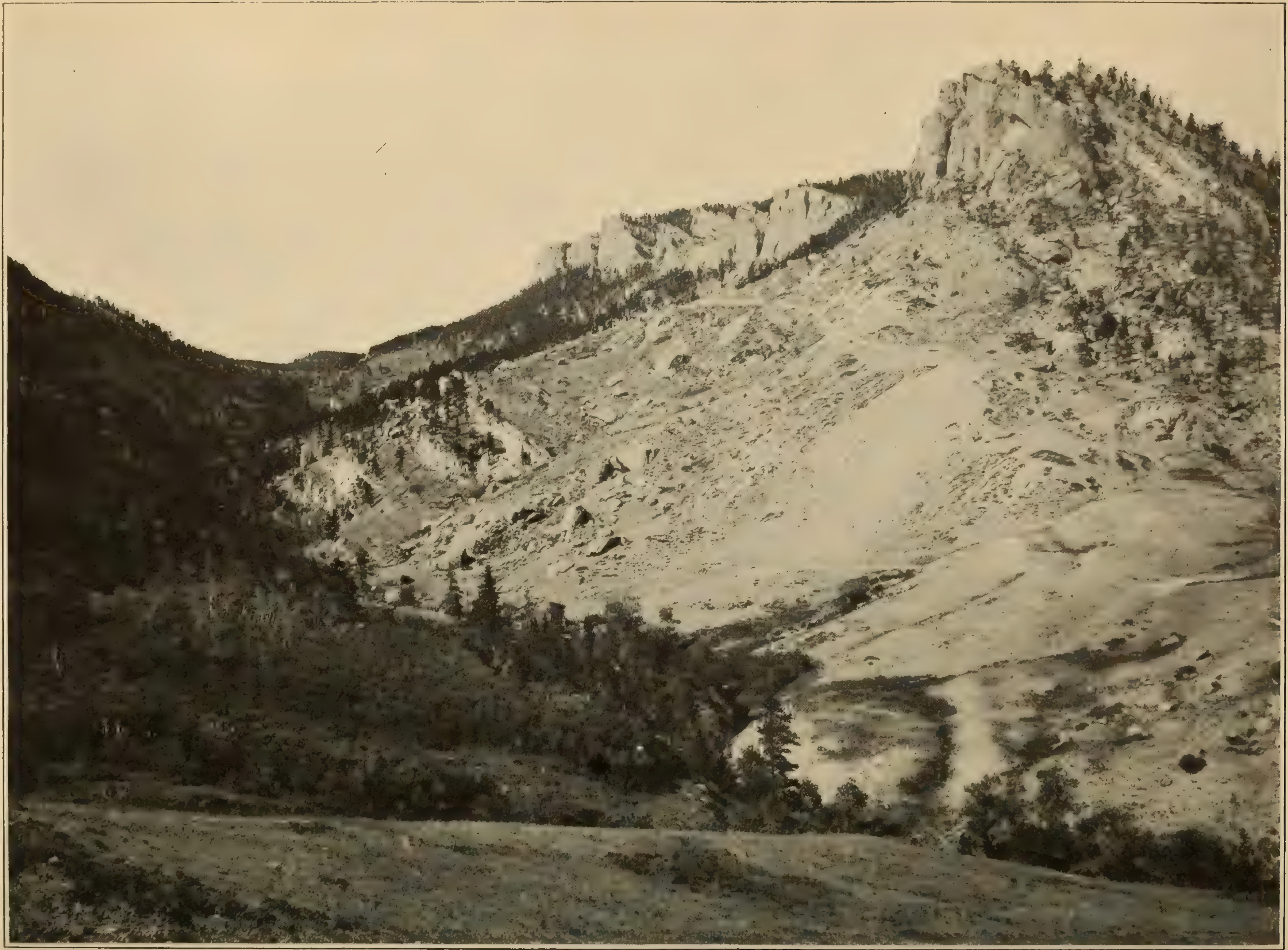
* Bull. Geol. Soc. Am., vol. 8, pp. 127–156.

† U. S. Geol. Survey Bull., no. 119, Washington, 1894.



CAMBRIAN AND ORDOVICIAN ROCKS ON EAST SLOPE OF BIGHORN MOUNTAINS, JOHNSON CREEK, NORTHWEST OF BUFFALO, WYOMING

Deadwood sandstones on granite to the left; shales and limestones in the slopes to right, surmounted by Bighorn limestone in characteristic cliffs

DEADWOOD FORMATION

As the lowest series in the Bighorn uplift so closely resembles the Deadwood formation of the northern Black hills, this name has been applied to it. Its thickness is greater, averaging from 900 to 1,000 feet, but the rocks comprise similar sandstones, shales, limestones, and conglomerates. At the base there are usually at least 10 to 30 feet of brown sandstone lying on the granite, and this member often is conglomeratic near the contact. Next above are gray and greenish gray shales, usually with thin sandstone or sandy shale intercalations, which ordinarily have a thickness of 250 to 300 feet. They are succeeded by a bed of coarse gray sandstone, averaging only from 25 to 40 feet in thickness, but apparently of wide extent. This sandstone is overlain by several hundred feet of shales and thin bedded sandstones containing considerable glauconite, at most localities, and a few thin layers of limestone. This series merges upward into an alternation of impure limestone and a very characteristic conglomerate of flat limestone pebbles, which are mostly green with glauconite on the surface, but vary from gray to pale pink inside. This limy series has a thickness of about 200 feet, and is generally succeeded abruptly by a bed of white sandstone in places 25 feet thick, which is arbitrarily regarded as the top of the Deadwood formation. There are very few local variations in the character of the formation, the principal change being in the thickness of the basal sandstones, which in some areas attain a thickness of 300 feet, as shown in plate 28. Fossils occur at various horizons, mostly in thin limestone layers somewhat above the middle of the formation, in the medial sandstone, and in the basal sandstone. The prominent forms are *Decellomus politus*, and *Ptychoparia oweni*, which occurs mainly in the basal sandstone.

BIGHORN LIMESTONE

This member is one of the most prominent of the sedimentary series in the Bighorn mountains, rising in high cliffs along the inner face of the limestone front range (see plate 28). Its principal mass consists of a hard, massive, impure limestone of light gray or faint buff color, with reticulating network of silica, which on weathering gives it a very coarse, irregularly pitted or honeycombed surface. The thickness ranges from 200 to 300 feet in greater part, and the bedding planes are mostly from 20 to 30 feet apart. It usually yields very few fossils, but those which have been found are of late Ordovician age. In its upper portion the rock becomes less massive and the top member included in the formation consists of some thin bedded, impure limestones, which at one locality northwest of Buffalo contain large numbers of fossils representing the Richmond fauna of the Upper Ordovician. The relations of this upper series are not well exposed and apparently it is not continuous. In some portions of the district the massive member of the Bighorn limestone is succeeded by fine grained, light colored limestones containing numerous corals, among which were recognized *Halysites catenulatus* and other forms.

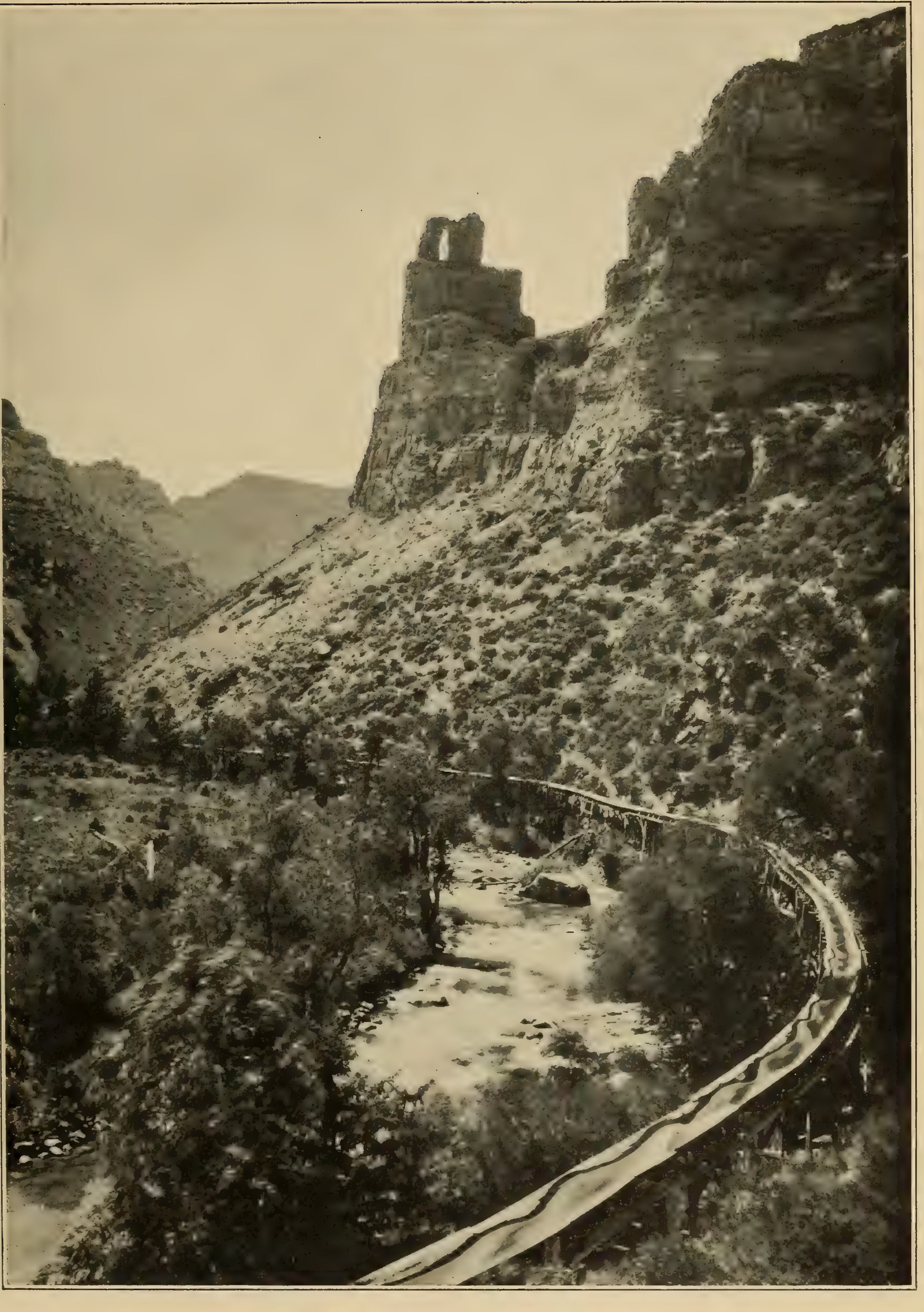
LITTLEHORN LIMESTONE

This formation comprises about 1,000 feet of beds, which constitute the greater part of the high front range of the Bighorn mountains. The rocks are mainly of light color and massively bedded. At the top there is a series of pure limestones, 100 feet or more in thickness, which weathers in typical castellated forms, as shown in plate 29. Many of the lower beds contain some sand admixture, and they are of darker color. Fossils of typical Mississippian forms occur at several horizons.

The formation is equivalent in the main to the Madison limestone of Montana and the Pahasapa limestone of the Black hills; but as the stratigraphic limits of the formation are somewhat indefinite, a local name is applied, derived from a great canyon on the east side of the range, in which the series is finely displayed. It is possible though not probable that in the basal portion of this formation the Silurian and Devonian are represented, for there is no evidence of stratigraphic break and no fossils have been discovered for the first 25 or 30 feet above the Ordovician fossils in the Bighorn limestone.

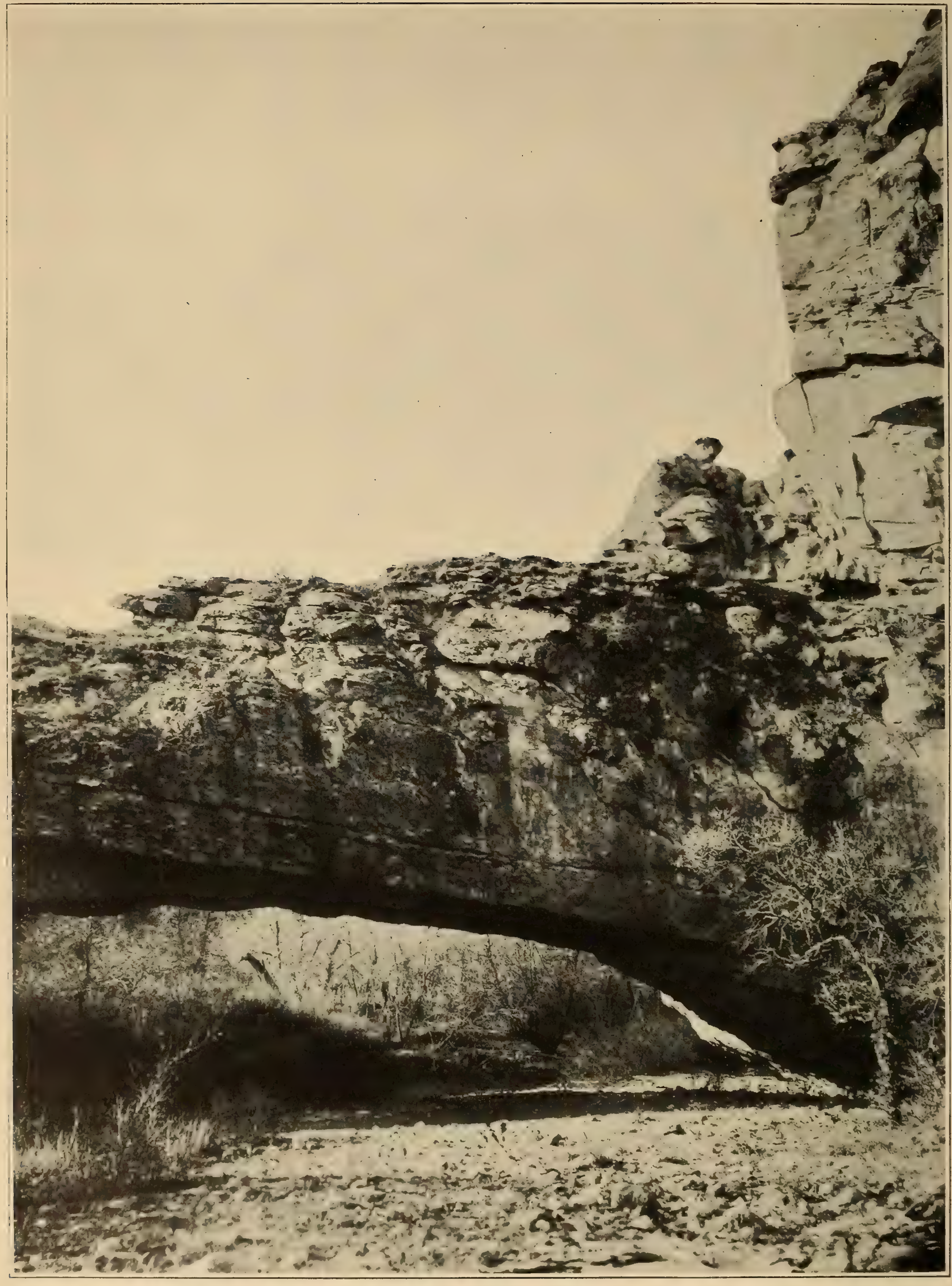
AMSDEN FORMATION

The uppermost member of the Bighorn front range has been separated as the Amsden formation, named from a branch of Tongue river west of Dayton. It consists of the somewhat variable succession of red shales, limestones, cherty and sandy members outcropping along the higher outer slopes of the range. Its thickness is about 150 feet near the Montana line, but it increases gradually to the southward to a maximum thickness of about 350 feet. Throughout its course the basal member is a red, sandy shale or fine grained red sandstone, from 50 to 100 feet thick—the amount gradually increasing to the southward—lying on the massive bluish gray limestone of the Littlehorn formation with no apparent unconformity. Next above is a somewhat variable series, including very compact, pure white limestones, several thin beds of gray sandstone, occasional thin bodies of red shale, and in the greater part of the region several thick beds of very cherty limestone. Some of the compact



LOOKING UP TONGUE RIVER, BIGHORN MOUNTAINS, WYOMING

Shows character and thickness of Littlehorn limestone, with characteristic erosion forms of its upper portion



NATURAL BRIDGE, LA PRELE CREEK, SOUTHWEST OF DOUGLAS, WYOMING

Shows massive structure and thickness of the Tensleep sandstone limestones have afforded a few fossils, which may possibly be Upper Carboniferous forms, but they are not decisive.

TENSLEEP SANDSTONE

There extends along the flanks of the Bighorn range a sheet of sandstone which probably represents the upper sandstone of the Minnelusa formation of the Black hills. Its thickness averages 200 feet for many miles, but near the Montana line it gradually thins to about 50 feet. Its white ledges are conspicuous features rising abruptly out of the red valley and extending for some distance up the mountain slopes, as shown in plate 31. No fossils have been discovered in it, but it is thought to represent some portion of the Upper Carboniferous.

The name is derived from the extensive exposures in the walls of the lower canyon of Tensleep creek.

CHUGWATER FORMATION

This name is proposed for the series of red beds extending along the foot of the Bighorn range southward through Wyoming and Colorado. In the Black Hills region the red beds are divided near their bottom by a limestone designated the Minnekahta, and although there appears to be a continuous representative of this limestone in the Bighorn uplift, a definite correlation can not be ventured, so that a name is required for the undivided red beds as a whole. The thickness also is greater than in the Black hills, the amount averaging about 1,250 feet.

The rocks are mainly bright red sandstones and sandy shales containing gypsum and near their bottom and top; thin beds of limestone. There are two beds of limestone near the base of the formation, one about 20 feet about the Tensleep sandstone, which varies in thickness from 2 to 4 feet, and consists of thinly laminated, pinkish limestone apparently unfossiliferous and strongly suggesting the Minnekahta limestone of the Black hills. About 40 feet higher there is another bed of impure limestone, usually of porous texture, averaging about 2 feet in thickness, but more extensively developed on the west side of the uplift. At the top of the formation there are usually several thin beds of limestone intercalated among the red, sandy shales in a series having in all a thickness of from 120 to 250 feet, the limestones varying from 2 to 10 feet in thickness. One of these beds is shown in plate 31. These limestones contain a few fossils, but they are not sufficiently distinct for accurate determination, as to whether they are of late Paleozoic or early Mesozoic age.

The name Chugwater is derived from Chugwater creek, on which there is presented an extensive series of red beds in the vicinity of Iron mountain, Wyoming.

SUNDANCE FORMATION

Typical marine Jurassic deposits, with an abundant fauna, extend continuously around the Bighorn uplift, and they are so similar to the deposits in the Black hills that the same name is applicable. The thickness averages about 300 feet and the succession comprises a sandy series below and a considerable thickness of greenish, fossiliferous shales above. At or near the base there usually is a hard, fossiliferous limestone layer having a thickness of from 3 to 5 feet, increasing locally to 25 feet. Next above are soft, sandy beds often containing large numbers of *Gryphæa calceola*, variety *nebrascensis.* The greenish shales above contain thin layers of highly fossiliferous limestones and a few thin, sandy layers.

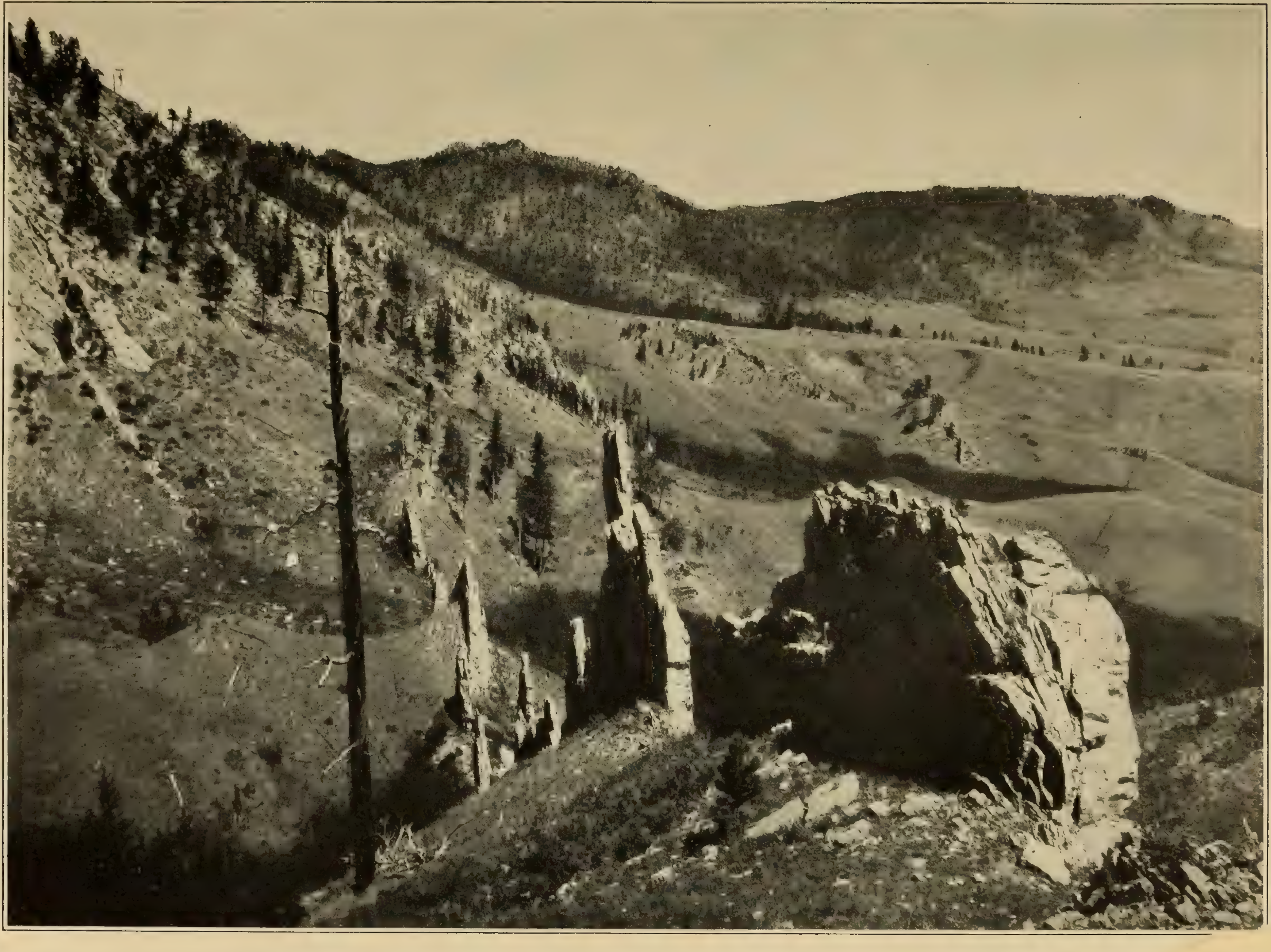
MORRISON FORMATION

This formation is easily recognized in the Bighorn uplift, presenting the distinctive features which it has in the Black hills and in Colorado. Shales preponderate, having the characteristic peculiar chalky appearance and massive or joint clay structure. The colors are mostly pale greenish or maroon, with darker clays at the summit. Several beds of light gray to buff sandstone are included, varying in thickness from 2 to 20 feet. The thickness of the formation is about 150 feet to the northward and 250 feet to the southward. The remains of Dinosaurs are abundant, but no other fossils were observed.

CLOVERLY FORMATION

Overlying the Morrison shales there is a thin bed of sandstone which, from its stratigraphic relations and character, is believed to represent the Lakota of the Black hills, overlain by and merging into clays resembling the Fuson formation. Owing, however, to the lack of any definite evidence as to the equivalency of these beds, and especially in the consideration of the apparent absence of deposits representing the Dakota sandstone above the clay, it has been thought best to give this series a separate designation. Accordingly "Cloverly" is proposed, a name derived from a postoffice on the eastern side of the Bighorn basin.

The sandstone member of the Cloverly formation usually gives rise to a line of knobs or low ridges on the divide along the eastern slope of the Bighorn uplift. Ordinarily it is a coarse grained, buff or dirty gray, cross-bedded, massive sandstone, averaging 30 feet in thickness, but varying from 10 to 60 feet. The overlying clay is rarely exposed, but in a few outcrops it is seen to be a reddish to ash-colored clay, locally



LIMESTONE LAYERS NEAR TOP OF CHUGWATER RED BEDS, NORTHWEST OF BUFFALO, WYOMING

View of east slope of Bighorn mountains; beds nearly vertical, offset by fault (see middle of view); slopes of Tensleep sandstone

of darker gray color and with a thickness of from 30 to 40 feet. Near the base of the sandstones there occur some very thin deposits of coal or coaly shale which sometimes contain remains of numerous flattened pine needles, as in the coal deposits of the lower beds of the Lakota of the Black hills.

BENTON FORMATION

The lower portion of the great mass of shales underlying the plains along the foot of the Bighorn mountains belongs in the Benton formation. It has an average thickness of about 1,300 feet. The subdivisions so obvious in the Black hills and in Colorado are not recognized, mainly owing to the absence of the Greenhorn limestone. However, the characteristic series of hard shales which weather to a light gray color are present, here nearly a thousand feet above the base of the formation, which indicates a great expansion of the lower third of the Graneros shales.

The basal member of the Benton consists of dark gray shales, in part sandy and of rusty brown color, with occasional thin beds of brown sandstone. Locally the sandstone expands into a bed of moderate thickness. It is possible that this portion of the formation represents the Dakota sandstone of other regions, but there is no direct evidence, and even if the few indistinct plant remains which it contains should prove to belong to the Dakota flora, that would be no more than we should expect in any shallow water deposits at the beginning of Benton times. There occurs in the upper part of this lower series, all along both sides of the Bighorn uplift, a zone of shales carrying round concretions varying from three-quarters of an inch to 2 inches in diameter in greater part, with radiated, crystalline structure and dark gray color. They consist mostly of phosphate of lime and appear to have the structure of marcasite and to be a replacement of that mineral.

Next above this lower member there are several hundred feet of dark shales, mostly fissile, which contain thin beds of sandstone and iron and lime concretions of typical lower Graneros character. These are overlain by a very characteristic series, about 150 feet thick, of hard, lighter gray shales and thin bedded sandstones which weather to a light gray color and form bare ridges of considerable prominence, notably Columbus peak, southwest of Parkman. Most of its beds contain large numbers of fish scales and occasional fish teeth and bones. By some observers this member was supposed to be Niobrara, but it lies below beds containing distinctive Benton fossils, and in other portions of eastern Wyoming it is exposed, having relations which indicate that its position is below the middle of the Graneros division of the Benton formation, or several hundred feet below the Greenhorn limestone horizon. This series I shall designate the Mowrie beds in the Bighorn region from Mowrie creek northwest of Buffalo. The top member of the Benton group comprises 200 feet or more of dark shales, with occasional fossiliferous layers containing Benton forms, and at their top there is a series from 20 to 30 feet thick, containing lens-shaped concretions, of buff color when weathered, in greater part 2 to 4 feet in diameter. These concretions carry occasional remains of *Prionotropis woolgari*, a species characteristic of the upper part of the Benton (Carlile) beds about the Black hills and elsewhere.

NIOBRARA FORMATION

The impure chalks and calcareous shales of this formation, which are so conspicuous in the region east and south, are not clearly distinct in the vicinity of the Bighorn mountains. Overlying the Prionotropis horizon above referred to, there are about 200 feet of light gray shales extending to the lowest dark gray shales containing Pierre fossils, which are believed to represent the Niobrara. *Ostrea congesta* was found in this series in the southern portion of the range, but was not observed northward.

PIERRE SHALE

This shale outcrops all along the Bighorn uplift, presenting its usual features of dark gray shales or clays containing occasional concretions filled with characteristic fossils. A few thin beds of sandstone occur in the northern part of the region, which develop to the southward and become conspicuous in the district south of Powder river, where they appear to constitute the principal oil-bearing horizon. The thickness of the formation varies from 2,000 to 3,000 feet, but it is possibly that this apparent unusual thickness is due partly to the crumpling of the beds in the steeper slopes of the uplift where most of my measurements were made.

FOX HILLS SANDSTONE

The Pierre shales give place rapidly to the Fox Hills sandstones, which have a thickness of 200 feet or more and consist mainly of fine grained, light buff rock, with numerous marine fossils. The bedding is massive in greater part, and the lithification of the sandstone is irregular, some portions being hard and the others so soft that it can be dug with a shovel. Hard concretions occur, mainly in elongated rounded forms of dark gray color. These concretions are similar to those which sometimes occur in the soft sandstones of the lower part of the Laramie formation, especially in the region west of the Black hills. The following fossils obtained from the Fox Hills sandstone near the Bighorn mountains were determined by Mr T. A. Stanton:

Cardium speciosum M. and H.; *Avicula linguiformis* Ev. and Sh.; *A. nebrascensis* Ev. and Sh.; *Ostrea glabra* M. and H.; *Liopistha* (*Cymella*) *undata* M. and H.; *Leptosolen*, n. sp.; *Cylichna* (?) sp.; *Baculites*, sp.; *Modiola*, sp.; *Prima lakesi* (?) White; *Leda* n. sp. (?); *Thracia subgracilis* Whitfield; *T. subtortuosa* M. and H.; *Lunatia subcrassa* M. and H.; *Sphæriola* (?) *cordata* M. and H.; *Tellina equilateralis* M. and H.

LARAMIE FORMATION

The wide expanse of plains lying between the foothills of the Bighorns and the Black hills is occupied by Laramie and overlying formations. The formation lies in a broad, flat bottomed basin, with steep dips on the west side on the slope of the Bighorn uplift. The thickness of the beds lying in this basin is not definitely ascertained, but it appears to be several thousand feet. The lower members are undoubtedly Laramie, but the upper ones probably extend into the Fort Union formation. The Laramie rocks are sandstones, sandy shales, and shales, with numerous beds of lignite. At the base there is usually a very characteristic member consisting of alternating shales and thin bedded, rusty sandstone. This in the northern portion of the region is succeeded by a conglomerate containing pebbles of limestones and of the characteristic flat pebble conglomerate of the Deadwood formation, derived from the mountains westward and indicating that there was uplift in the region in early Laramie times. This conglomerate begins west of Sheridan and extends southward to Crazywoman creek. The conglomerate is succeeded by sandstones and shales, with coal beds, which occur at various horizons.

Laramie Range

GENERAL RELATION OF THE FORMATIONS

South of the Bighorn uplift there is a transverse syncline, and it is not until the north end of the Laramie range is reached that the older rocks again appear. In this range some of the formations present features different from those in the uplifts to the north and east. The Cambrian appears to be present, but it is thin and soon disappears, and to the southward there is a gradual overlap of the Upper Carboniferous rocks onto the granites of the main uplift. The Mesozoic rocks do not exhibit much change. The geology of the southern part of this region was outlined by the Fortieth Parallel Survey, and F. V. Hayden described a few details at the northern end of the range. Along portions of the slopes the older formations are covered by later Tertiary deposits. The following list sets forth the principal features of the formation in southeastern Wyoming.

	Formations.	Principal characters.	Thickness. *Feet.*
Cretaceous	Laramie	Sandstones, with coal and shales.	500 or more
	Fox Hills	Sandstones	200 ±
	Pierre	Dark shales	1,000 or more
	Niobrara	Calcareous shale	100 ±
	Benton	Dark shales and sandstones.	800 ±
	Dakota-Lakota	Buff massive sandstone and conglomerate, with shale intercalations.	200 ±
	Morrison	Light colored massive shale and gray sandstone.	200–475
Jurassic	Sundance	Greenish shales and buff sandstones; local gypsum beds.	
Triassic (?) or Permian.	Chugwater	Red shales and red sandstones, with gypsum and limestone.	580–800
Carboniferous (Pennsylvanian).	Tensleep	Gray massive sandstone	60
		Gray massive limestone; some sandstone.	200–1,000
Cambrian (?)		Coarse, hard, massive, gray conglomeratic sandstone.	0–100
Archean or Algonkian.		Granites and schists.	

CAMBRIAN

In Casper mountain and associated ridges at the northern end of the Laramie range the basal member of the sedimentary series is a gray to brown sandstone, conglomeratic at the base, which is supposed to be of Cambrian age, although no organic remains were discovered in it. It has a thickness of 100 feet for some distance, but soon thins out to the eastward.

PENNSYLVANIAN

There extends along the east slope of the Laramie range a series of limestones, with some local beds of sandstone, all of which appear to be of Upper Carboniferous age. Fossils of this age have been reported by F. V. Hayden on Boxelder and La Prele creeks, and by A. Hague in the region west and northwest of Cheyenne. These remains were not found in the lowermost beds, so there is a possibility that earlier Carboniferous or even older sediments are represented; but this is thought to be exceedingly improbable. The limestones have a thickness of about 250 feet at

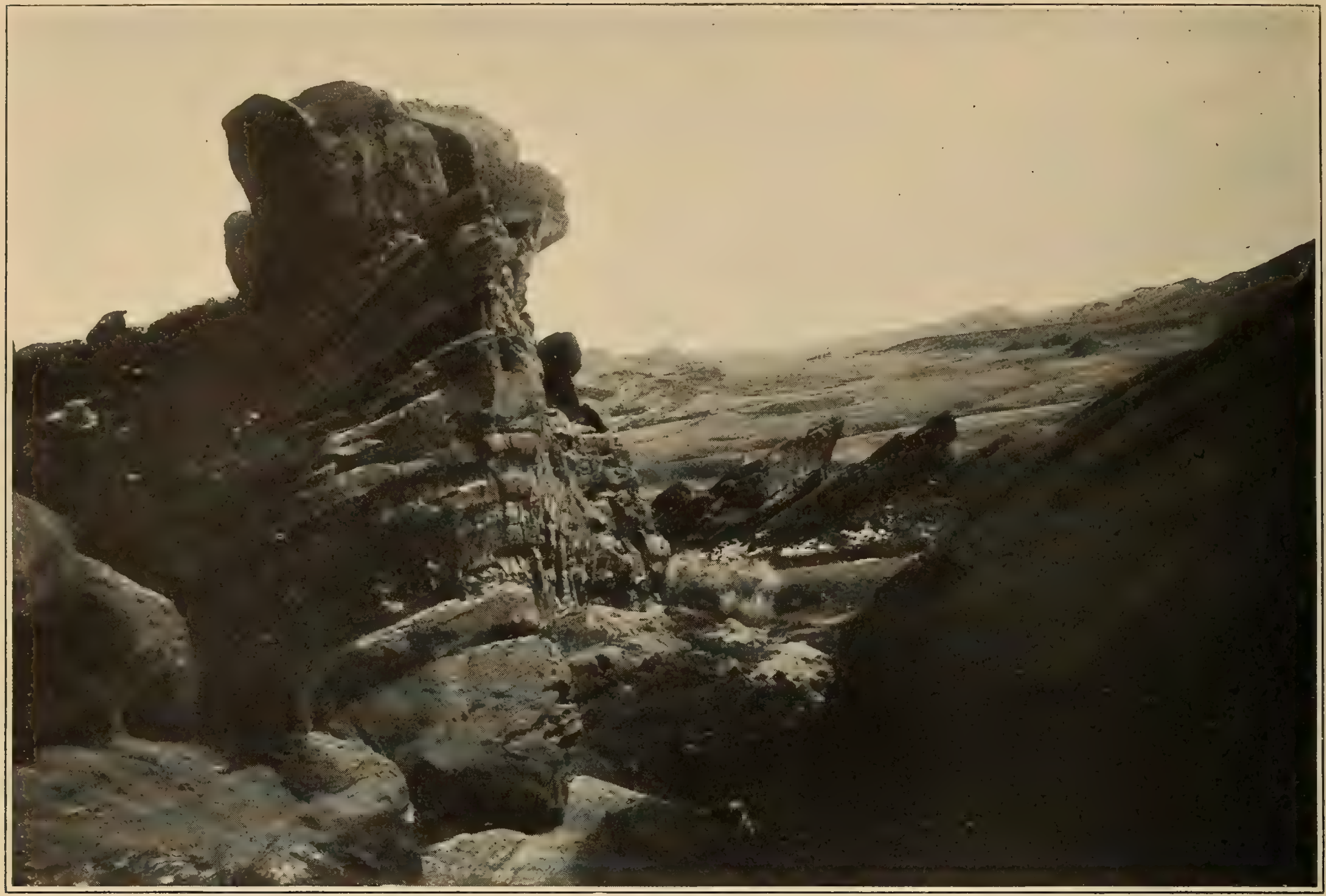


FIGURE 1.—EASTERN SLOPE OF ROCKY MOUNTAINS, MORRISON, COLORADO

Lower Wyoming red grits in foreground; hogbacks of "Dakota" sandstone in distance

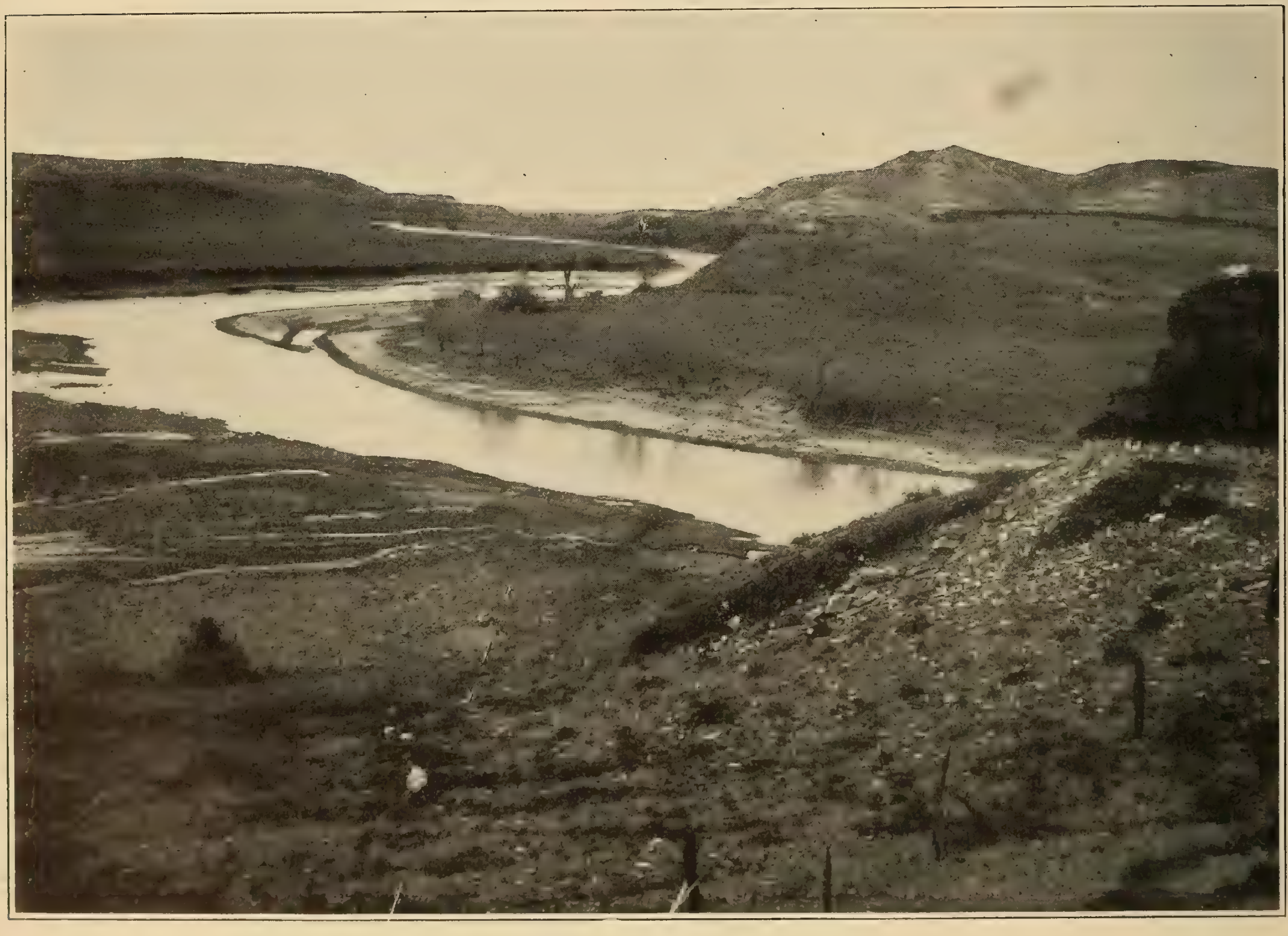


FIGURE 2.—NORTH PLATTE RIVER, SOUTH OF DOUGLAS, WYOMING

Red beds in river banks, overlain by Sundance; Morrison and Dakota formations in distance; Minnekahta limestone in the right foreground

EASTERN SLOPE OF ROCKY MOUNTAINS AND NORTH PLATTE RIVER the north, but the amount increases to over three times that amount in southern Wyoming, where there are extensive intercalations of beds of gray and reddish sandstones from 5 to 40 feet thick. Except in the Casper Mountain area, they lie directly on the old schists and granites.

TENSLEEP SANDSTONE

This member, which I first differentiated in the Bighorn region, is a conspicuous feature in portions of the Laramie range, especially to the northward, though it appears to be traceable far to the southward. In the Casper range it is a massive, coarse grained, porous sandstone, varying in color from light gray to dark gray and brown, and having a thickness of 50 feet or more (see plate 30). It appears again from under the Tertiary on Chugwater creek, near Iron Mountain station, and at intervals southward, but is much less distinct in this portion of the region. The formation underlying the typical gypsiferous Red beds west of Iron Mountain station is 65 feet of brownish red, soft sandstones of massive texture containing two thin beds of limestone. On Horse creek there is a similar succession and thickness of sandstone, excepting that only one 5-foot bed of limestone is included.

CHUGWATER FORMATION

The " Red beds " are exposed on the south slope of Casper mountain and in the valleys of La Prele, La Bonte, Sybylle, Chugwater, and Horse creeks. In the main they present the usual characteristics of the gypsiferous red deposits of the Black Hills and Bighorn regions. Their thickness is about 550 feet to the north and about 800 feet in the Chugwater and Horse Creek valleys. To the northward the Minnekahta limestone of the Black Hills series is represented with unmistakable characteristics, lying about 80 feet above the Tensleep sandstone, the intervening red sandy shales having the character of the Opeche formation. There are excellent exposures of these members in the gorge at the east end of Casper mountain, on La Prele creek, and on the North Platte river, 6 miles south of Douglas. The last locality is shown in figure 2, plate 32. The Minnekahta limestone is mostly thin bedded and of a purplish tint, and its thickness is from 20 to 25 feet. At the east end of Casper mountain there is a 15-foot layer of cherty limestone, 80 feet above the Minnekahta limestone, a feature which is often seen in the Bighorn sections. At the top of the Chugwater formation at this locality there is a 20-foot limestone layer which probably represents the alternations of limestone and red shales at the top of the same formation in the Bighorn region. Local deposits of gypsum occur.

The Minnekahta limestone is massive in general appearance, but is very thin bedded and weathers out in thin slabs. On the North Platte river, south of Douglas, its upper portion is mottled dark gray, and at the top there are 5 feet of more massive limestones of light color, which is rather an unusual feature. Owing to overlap by Tertiary deposits, all of the Chugwater formation does not appear again until Chugwater creek is reached. Here its thickness is from 700 to 800 feet, measured in beds dipping from 43 to 78 degrees. The rocks are the usual red sandy shales, grading into soft, red sandstones. Near the middle of the formation are two thin layers of limestones, which apparently are too high to represent the Minnekahta limestone, a most unusual sequence not elsewhere observed in the region to which this paper relates.

In the extensive exposures on Horse creek there is a 20-foot ledge of limestone 260 feet above the base of the formation which is strongly suggestive of the Minnekahta. A bed of porous, sandy limestone 4 feet thick lies 70 feet higher, as in the region northward and in the Bighorns, and 100 feet higher is a 5-foot bed of massive white limestone. At the top of the formation in this region there is a bed of pale reddish brown massive sandstone, which continues far to the southward. Between the base of the Chugwater formation and the Upper Carboniferous limestone, on both Chugwater and Horse creeks, there are 65 feet of massive soft sandstone of reddish color, with thin beds of limestone, which may possibly belong to the Chugwater formation, but, as explained above, this series is believed to represent the Tensleep sandstone.

SUNDANCE FORMATION

This formation extends along the slope of the Laramie range, presenting its usual characteristics to the northward, but thinning rapidly to the southward. In extensive exposures at the east end of Casper mountain it has a thickness of about 350 feet. At the base, overlying the limestone which is supposed to represent the top of the Chugwater red beds, there are 20 feet or more of white to red sandstones, then a few feet of buff sandstones and shales with an 8-foot bed of gypsum, and finally an upper series of dark shales with limestone layers and concretions filled with characteristic fossils, including many *Belemnites densus.*

Along North Platte river, in its big bend south of Douglas (figure 2, plate 32) and to the west on Wagonhound creek, the succession is as follows from the bottom up: 30 feet or more of massive gray sandstones; 30 feet of pale greenish sandy shales; 5 feet of soft greenish massive sandstone; 40 feet of bright reddish sandy beds; 15 feet of massive buff sandstone; and at the top about 200 feet of green shales with a few thin beds of sandstone and limestone containing many upper Jurassic fossils.

The formation appears again on Chugwater and Horse creeks, consisting of an upper series 30 feet thick of soft, slabby sandstones, gray at the base and buff toward the top, with ripple-marked layers and much intercalated shale, and a lower series 50 feet thick, mostly of green and gray shale, with layers of soft, thin bedded, greenish gray sandstones lying on the Chugwater formation.

MORRISON FORMATION

The Morrison formation appears to extend continuously along the Laramie range, presenting its usual characteristics of a joint clay or massive shale, mostly of greenish gray color with some portions of maroon tint. Occasional thin beds of light colored sandstone are included, and limestones are numerous in the lower portion of the formation, especially to the southward. In the vicinity of Casper mountain the thickness is not much more than 100 feet, but on the Chugwater and near Horse creek it is 300 feet.

LAKOTA-DAKOTA

The Morrison formation is everywhere overlain by coarse grained buff sandstones, which have been designated "Dakota," but probably include the Lower Cretaceous members, Fuson and Lakota. Their thickness is 100 to 150 feet. At the base there is usually more or less conglomerate merging upward into a series of coarse sandstone; then follows a bed of shales, varying in color from dark gray to bright purplish red, strongly suggestive of the Fuson formation, and at the top a thick mass of coarse brown to gray sandstone often containing considerable ironstone. In many of the hogback ranges there is a third sandstone member, but it probably belongs in the lower part of the Benton, for it is always underlain by a considerable thickness of dark colored shales.

THE BENTON GROUP

The formations of the Benton group are extensively exhibited about the northern end of the Laramie range and on Chugwater, Horse, and Lodgepole creeks. As in other regions, they consist mainly of shale of dark color, but the component formations present many of their distinctive features. The Mowrie series of hard shales, which weather to light gray color, are distinct throughout, lying about 500 feet above the Dakota sandstone at the north end of the range and about 200 feet above to the southward. As in the Black Hills region, a sandstone bed usually occurs in the lower portion of the Graneros shales, a feature especially conspicuous on Chugwater and Horse creeks. Here the thickness of this sandstone is about 25 feet, and it is underlain by 140 to 150 feet of dark shales lying on typical Dakota sandstone. Thirty feet above the Graneros sandstone are the Mowrie beds. The Greenhorn limestone is not clearly defined at the north end of the range, but it appears southward near Horse creek, having a thickness of only 3 inches, separated from the Mowrie beds by 450 feet of dark shales. The rock is a sandy limestone containing numerous *Inoceramus labiatus*. Next above are 230 feet of Carlile beds containing near the top concretions carrying *Prionotropis woolgari*, the fossil which characterizes this horizon throughout the Northwest. The following section gives the details of the Benton beds west of Horse Creek station, Wyoming:

Section of Benton Beds West of Horse Creek Station, Wyoming

		Feet
Niobrara	Limestone	
Carlile	Black shale	10
	Sandstone and sandy shale	20
	Gray shales, with concretions containing Prionotropis near top	200
Greenhorn	Sandy limestone, with *Inoceramus labiatus*	¼
Graneros	Shales, dark and fissile below	450
	Hard shales and thin bedded hard sandstones, weathering light gray, with fish scales (Mowrie beds)	80
	Dark shale	30
	Hard coarse sandstone, massive	25
	Dark shales, fissile to soft	150
Dakota	Sandstone, buff, coarse, mostly soft	20 +

At the north end of the range the Mowrie beds are overlain by about 500 feet of dark shales extending to a very conspicuous sandstone layer 20 feet or more in thickness, which is very fossiliferous in the Muddy Creek valley. The principal forms were determined by Mr T. W. Stanton as *Inoceramus fragilis* and *Cardium panpereulina*. This sandstone is overlain by several hundred feet of dark shales with some thin layers of sandstones and horizons of concretions, representatives of the Carlile beds.

NIOBRARA FORMATION

The chalky deposits of the Niobrara extend northward from Colorado, but have greatly diminished thickness near the northern end of the Laramie range. On Horse creek and the Chugwater the formation consists of limestone and impure chalk, grading into limy shale, its basal member being a soft, light gray, massive limestone filled with a typical *Inoceramus deformis*. There are two other limestone beds above, separated by limy shales, while at the top is the usual chalky bed which weathers to a bright straw or pale ocher color and contains thin limestone masses consisting of colonies of *Ostrea congesta.* The thickness is about 350 feet. Exposures at the north end of the range are not complete, owing to Tertiary overlap, but the total thickness probably is not great. The material is a limy shale or impure chalk, with the characteristic light straw color in weathered outcrops and the thin beds of hard limestone filled with *Ostrea congesta.*

PIERRE SHALE

This shale outcrops continuously from the Bighorns to the north end of the Laramie range, presenting its usual characteristics, a great mass of dark gray shale with numerous concretions containing distinctive fossils. In some localities local beds of sandstone are included. The formation is exposed at the foot of the mountains, on Horse and Chugwater creeks, where its thickness appears to be more than 2,500 feet.

FOX HILLS FORMATION

Sandstones of the Fox hills approach close to the north end of the Laramie range some distance east of Casper, and they are also exposed in a small area at Horse Creek station. The rocks are soft, impure sandstones and sandy clays with more or less concretionary structure. Abundant fossils were observed 2 miles south of Glenrock.

Hartville Uplift

GENERAL CHARACTERISTICS AND SECTION

The Rocky Mountain front range and the Black Hills uplift are connected by an anticline which would have considerable prominence topographically were it not for the thick covering of Tertiary deposits. It branches from the main Laramie uplift north of Iron mountain, is extensively bared by erosion along the North Platte river and northward for some distance in the Hartville region, and is marked by the prominent peak of granite known as "Rawhide butte" and by numerous minor outcrops of schists, limestone, and Cretaceous rocks in the eastern portion of Converse county, Wyoming.

This anticline, which may be designated the Hartville uplift, affords extensive exposures, which throw much light on the stratigraphic variations between the Black hills and the Rocky mountains. These details have been studied with special care in the area of the Hartville quadrangle in greater part by Dr W. S. Tangier Smith, the results of which are published in the Hartville folio.*

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*U. S. Geol. Survey folio no. 91.

In the Hartville region the Lower Carboniferous rocks are seen lying on the pre-Cambrian crystalline rocks, and many interesting features of overlap are exhibited. The most extensive exposures are in the deep gorge cut by the North Platte river from Guernsey westward, and the Cretaceous rocks are clearly displayed in an anticlinal ridge which rises on the east side of Old Woman creek.

Generalized Section of the Rocks of the Hartville Uplift

Age.	Formation.	Principal characteristics.	Thickness.
			Feet.
Cretaceous	Pierre	Dark shales, with limestone concretions.	1,200
	Niobrara	Impure chalk and limy shales	250
	Carlile	Gray shales, with concretions and thin sandstone layers.	425
	Greenhorn	Hard, impure, slabby limestone	50
	Graneros	Dark shales, with local sandstone bed near base.	800 ±
	Dakota	Buff, gray, and reddish, massive coarse grained sandstone.	60 ±
	Fuson	Gray, buff, and maroon shales and sandstone.	60
	Minnewaste	Gray limestone	5
	Lakota	Coarse, buff, massive, cross-bedded sandstone.	100
	Morrison	Pale green, gray, purple, and black clay, with thin limestone.	100
Jurassic	Sundance	Buff sandstones and gray clays	200
Triassic (?) or Permian.	Spearfish	Bright, reddish brown, sandy shales and thin bedded sandstone, with gypsum.	450
Carboniferous.	Minnekahta (Permian).	Thin bedded gray limestone	20
	Opeche (Permian)	Bright red, thin bedded sandstone, with red sandy shale.	60
	Hartville (Pennsylvanian to Mississippian).	Massive gray limestone, in part cherty, some beds very sandy; also white, gray, buff, and red sandstone, red shale, and gray limestone near base, and basal red quartzite.	630
	Guernsey (Mississippian).	Conglomeratic quartzite, with overlying sandstone and massive gray limestone.	150
Algonkian		Granites and schists.	

GUERNSEY FORMATION

The Guernsey formation consists mainly of limestone with a thin series of alternating sandstones and limestones in its lower portion, and at the base a white to pinkish conglomeratic quartzite lying on a relatively smooth surface of Algonkian schists and granites. The thickness ranges from about 75 feet to 200 feet, the smaller amount being due mainly to the removal of upper members by erosion prior to the deposition of the overlying formation. The following fossils, which are Mississippian in age, were determined by Dr G. H. Girty:

Eumetria verneuiliana ?
Productus gallatinensis.
Productus lævicosta.
Productus semireticulatus ?
Pugnax sp.
Seminula subquadrata.
Spirifer cf. *Keokuk.*
Spirifer striatus var. *madisonensis.*
Zaphrentis sp.

It is believed that this formation represents the attenuated and eroded southern extension of the Pahasapa and Little Horn limestones of the region north.

HARTVILLE FORMATION

This formation consists of a thick mass of limestone, having at the base a characteristic deposit of brownish red quartzite from 50 to 100 feet thick, lying on the irregularly eroded surface of the Guernsey formation. The erosion separating these two formations represents a portion of earlier Carboniferous times. The limestones contain sandy beds, some sandy admixture, and occasional thin layers of shale. They are fine grained and compact, generally of light gray color, and at some horizons there are thin sheets of chert and chert nodules. The sandstones are medium fine grained, with calcareous cement, and occur mostly in beds less than 10 feet thick, although locally they are thicker. The formation is most extensively exposed in the deep canyon of North Platte river above Guernsey. The following Pennsylvanian fossils were obtained from between 300 and 500 feet above the base of the formation in the canyon of Platte river:

Ambocoelia? sp.
Archæocidaris spines.
Aviculopecten occidentalis.
Derbya crassa.
Euomphalus sp.
Fusilina cylindrica.
Marginifera splendens ?
Orthothetes (*or Derbya*).
Productus æquicostatus.
Productus cf. inflatus.
Productus prattentianus.
Productus punctatus.
Productus semireticulatus.
Seminula subtilita.
Spirifer rockymontanus.

From the lower portion of the formation there were obtained several of the Lower Carboniferous (Mississippian) species found in the Guernsey formation, so that the lower beds represent products of deposition of earlier Carboniferous times. The red shales in the lower portion of this formation, including its basal red quartzite, may represent the upper red shale member underlying the Minnelusa formation of the Black Hills region.

OPECHE FORMATION

This member, 60 feet in thickness, is seen west of Guernsey, lying on the massive, white sandstone at the top of the Hartville formation, a member which probably represents the Tensleep sandstone.

MINNEKAHTA LIMESTONE

A small but characteristic exposure of this limestone was observed with the underlying Opeche red beds north of North Platte river, 15 miles northwest of Guernsey.

SPEARFISH FORMATION

The Spearfish red beds are exposed at the above mentioned locality 15 miles northwest of Guernsey, with an estimated thickness of about 450 feet.

SUNDANCE FORMATION

This formation appears in the banks of North Platte river northwest of Guernsey and for some distance northward. The lower 145 feet are sandstones with a few thin beds of shales, over which there are 60 feet of interbedded, slabby sandstones and clays, all containing characteristic marine Jurassic fossils. The top of the formation appears in a canyon crossing the anticline on Old Woman creek.

MORRISON FORMATION

The characteristic greenish and purplish, massive clays of this formation appear in the localities above mentioned, west of Guernsey and on Old Woman creek.

LAKOTA-DAKOTA

The sandstones of these formations appear in the basin northwest of Guernsey, and they constitute the higher part of the anticlinal range on the east side of Old Woman creek. The thickness is from 150 to 350 feet, comprising hard, massive, coarse grained sandstones, which to the northward are separated by gray and purple clays and thin bedded sandstones believed to represent the Fuson formation of the Black hills.

In the sandstones there are thin conglomeratic streaks, general cross-bedding, and the colors are predominately buff to dirty gray. In the uppermost sandstone there is usually more or less ironstone. On the east side of Old Woman creek the Fuson formation is underlain by a thin bed of limestone, which probably represents the Minnewaste limestone of the southern Black hills.

BENTON GROUP

In the basin northwest of Guernsey the Graneros member of this group is exposed to a thickness of about 120 feet, and the entire group is finely exhibited in the anticline on the east side of Old Woman creek, dipping steeply to the west. Here the lower formation, Graneros, consists of dark shales 800 feet thick. A thin bed of hard sandstone occurs about 100 feet above the base, a feature which is also seen northwest of Guernsey, where this sandstone is the uppermost member exposed. The Graneros shales are capped by the Greenhorn limestone, consisting of about 50 feet of thin bedded, impure limestone, weathering out in slabs of dirty buff color and usually containing large numbers of *Inoceramus labiatus.* The overlying Carlile formation has a thickness of about 425 feet, consisting of shales of gray color, with occasional thin beds of sandstone, and toward the top the characteristic horizon of biscuit-shaped concretions.

NIOBRARA FORMATION

This formation is exposed along the Old Woman Creek anticline, having a thickness of 250 feet. It consists of impure chalk and limy shale of lead gray color in fresh exposures, but weathers to a bright, pale straw color, a highly characteristic feature which renders its outcrops very conspicuous. The formation contains occasional thin layers of limestone filled with the characteristic fossil, *Ostrea congesta.*

PIERRE SHALE

This formation probably underlies the Arikaree formation along the east side of the uplift from Iron Mountain station northward, and doubtless also the western side of the uplift north of Orin junction, but it is exposed only in the lowlands north of the foot of Pine ridge. There it is found on both sides of the anticline of Old Woman creek, extending to Cheyenne river and thence along the slopes of the Black Hills uplift. The beds dip steeply along the Old Woman Creek valley, where a cross-section measurement gave a thickness of 1,200 feet. The rocks consist of a monotonous series of dark gray shales, with occasional concretions, and 200 feet below the top there is a zone of concretions consisting of limestone filled with *Lucina occidentalis.* As in other regions, the limestone concretions of this upper zone weather out in characteristic tepee-shaped forms which have been designated "Tepee buttes."

The Pierre shale is overlain by the Fox Hills and Laramie sandstones, which extend far to the north and west in the great basin lying between the Black Hills and the Bighorn mountains.

ROCKY MOUNTAIN FRONT RANGE IN COLORADO

INTRODUCTORY

The sedimentary rocks are steeply upturned along the Rocky mountains, presenting extensive exposures along the foothill ridges. They have been described by various writers in the reports of the Hayden survey, in the monograph on the Denver basin, in folios of the U. S. Geological Survey, and in other publications.

During the past two years I have examined the greater part of the district with a view of determining details which have not been set forth by previous observers, and especially to correlate some of the strata in their extension from one portion of the district to another. The special features to which consideration was given were the stratigraphic relations of the Red beds in their extension southward from Wyoming, and especially to ascertain whether or not the upper gypsiferous series includes a representative of the Minnekahta limestone and is underlain by the Tensleep sandstone as in the region northward. Another matter of importance was the investigation of the manner in which the lower Red beds are related to the Upper Carboniferous limestones of the southern Wyoming region, and I was interested to trace northward the subdivisions of the Benton group established by Mr G. K. Gilbert in the Arkansas Valley region. Attention also was given to the manner in which the marine Jurassic terminated in northern Colorado. All these inquiries yielded results which I believe throw light on the stratigraphy.

FORMATIONS OF THE FRONT RANGE

In the following table is given a list of the formations recognized in the Front range, and in plates 23, 35, and 36 some of the regional variations are shown:

Table of Paleozoic and Mesozoic formations of eastern Colorado

Age.	Formations.	Principal characters.	Average thickness.
			Feet.
Tertiary	Denver	Conglomerates, sandstones, and clays.	1,450
	Arapahoe	Clay on thick basal series of conglomerates.	800
Cretaceous	Laramie	Clays, with sandstone layers and coal beds.	1,000
	Fox Hills	Sandy shales, with sandstone at top.	100–1,000
	Pierre	Dark shales, with local sandstone layers.	1,500–7,500?
	Niobrara	Light colored soft limestones and limy clays.	350– 700
	Benton: Carlile	Dark shales, with sandstone at top.	200
	Greenhorn	Slabby limestones	30
	Graneros	Dark shales, with local sandstone layers in lower part.	400– 500
	Dakota	Gray sandstones, sometimes conglomeratic, fireclay in middle.	350
	Morrison	Gray to maroon "joint clay," with limestone and sandstone layers.	200
	Comanche series	Soft sandstone and sandy clay.	20
Triassic (?) and Permian (?).	Upper Wyoming (Chugwater).	Bright red sandy shales, with thin limestone layers and gypsum, reddish sandstone at top.	400
Pennsylvanian.	Lower Wyoming (Fountain).	Coarse red sandstones and conglomerates.	600–1,200
Lower Mississippian.	Millsap	Gray and purplish limestone.	30– 200
Ordovician	Fremont	Gray to pinkish dolomite, uneven grain.	100
	Harding	Fine, even grained, gray to pink sandstone, some shale.	100
	Manitou	Reddish dolomite	100– 270
Cambrian		Reddish sandstone	40– 100
Algonkian and Archean.		Granite and schists	

CAMBRIAN

Rocks of Cambrian age are exposed in the Manitou embayment west of Colorado Springs and in a smaller area north of Canyon City. Elsewhere along the Front range post-Cambrian rocks appear to lie directly on old granites and schists. In the Manitou Park area there are about 100 feet of sandstones mostly of light color, containing upper Cambrian fossils. A similar sandstone exposed along the slopes west of the Garden of the Gods and, according to Willis T. Lee, also appearing in Deadman creek, is presumably of the same age, for it is overlain by Ordovician limestones. North of Canyon City there are basal quartzites, with an overlying cherty limestone which yields an upper Cambrian trilobite, Ptychoparia.

ORDOVICIAN

Small areas of Ordovician rocks occur in the Manitou embayment, Trout Creek valley, Perry park, and west and north of Canyon City. In most casses they lie on a thin mass of Cambrian sandstone or quartzite, but locally overlap on the granites and schists. In the Canyon City region the Ordovician is represented by three formations, the Manitou limestone, Harding sandstone, and Fremont limestone. These have been described in detail by Mr C. D. Walcott,* mainly in connection with the occurrence of fish remains, and by Dr C.W. Cross in the region northeast of Canyon City, in the Pike's Peak folio.

The Manitou limestone, the basal member of the series, consists of fine grained pink or reddish dolomite, less than 100 feet thick, which, in the Manitou region, contains Ophileta, Camarella, and other characteristic Ordovician fossils.

The Harding sandstone consists mainly of fine, even grained, granular sandstone, mostly of light color, having a maximum thickness of about 100 feet. At Canyon City the formation is 80 feet thick, and consists of gray, reddish, and purplish brown sandstones and shales, carrying the fish remains and many molluscan fossils of early Trenton age. At this place it overlaps on the gneiss, but to the southward rests with apparent conformity on the Manitou limestone for some distance. A small outlier of sandstone apparently of this formation was found southeast of Canyon City by G. K. Gilbert. Overlying the Harding sandstone with apparent conformity there occurs a bluish gray or pinkish dolomite of uneven grain, known as the Fremont limestone. It is about 100 feet thick in Garden park, north of Canyon City, and 270 feet near Canyon City, the increased thickness being partly due to the development of an upper fossiliferous member. In Garden park it is characterized especially by the coral *Halysites catenulatus*, and it also contains a molluscan fauna like that of the upper Trenton in New York. Its occurrence appears to be restricted to a small area in Garden park and vicinity and a narrow outcrop extending southward past Canyon City.

At Manitou and for some distance northward and in the valley of Trout brook the "Red beds" are underlain for some distance by the

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* Bull. Geol. Soc. Am., vol. 3, pp. 153-167.

Manitou limestone yielding Ordovician fossils. Thirty feet of beds, believed to represent this formation, occur at Glen Eyrie, and on Deadman creek a few miles south of Palmer lake Mr Willis T. Lee has discovered some cherty limestones with red clay intercalations yielding *Dalmanella testudinaria*. Another exposure of this limestone which has yielded no fossils occurs in the southern portion of Perry park.

The Silurian and Devonian appear to be entirely lacking in the Rocky Mountain front range, although possibly during these periods deposits were laid down which were removed by the vigorous erosion which preceded Carboniferous deposition.

MILLSAP LIMESTONE

This representative of the Lower Carboniferous (Mississippian) outcrops in detached basins in Perry park, about Manitou, in the district north of Canyon City, and on the slope of the Wet mountains southwest of Pueblo. It is everywhere distinctly separable from the overlying Red beds which widely overlap its edges. The limestones are most conspicuous about Manitou, especially in Williams canyon, where they present a thickness of from 200 to 300 feet. They are of gray, purplish, and yellowish tints. The exposures in Perry park have been described by Mr Willis T. Lee* as follows:

> "At the base of the formation there are 40 feet of coarse, crumbling sandstones, conglomeratic in places and mottled in varying shades of red and gray, a member which may be older than Carboniferous. Next above is a series, 10 to 15 feet thick, of deep red to white, cherty limestone in layers alternating with red shale, and one of these limestone layers near the top was found to contain the following fossils: *Orthothetes inequalis*, *Spirifer centronatus*, *Spirifer* sp., *Spiriferina solidirostris* (?), *Seminula subquadrata* (?), *Cranæna* n. sp., *Myalina arkansasana*, *Aviculopecten* sp."

In the vicinity of Canyon City and in the small area where the formation again appears at the head of Garden park, the limestone is a thinly bedded, variegated, dolomitic rock with a few thin sandstone layers, and in its upper portion there are chert nodules which carry *Spirifera rockymontana* and "*Athyris subtilita*" (Mississippian forms). In an outlier 25 miles southwest of Pueblo, described by Mr Gilbert, there is a thickness of 200 feet of gray and purplish limestones, with some shale in their lower part. *Spirifera rockymontana* occurs near the middle of this series at this locality.

RED BEDS

The Red beds along the Rocky Mountain front are distinctly separable into two series, which in the Denver region have been classified by

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*Am. Geologist, vol. 29, pp. 97-98.

Eldridge as upper Wyoming and lower Wyoming. The geologists of the Hayden survey perceived the distinction between the two, classifying the upper series as Triassic in some cases and in others joining them to the Morrison under the head of Jurassic.

The upper series consists mainly of fine grained red sediments, with beds of gypsum and thin beds of limestone, which I believe represent the southern extension of the Chugwater formation described on previous pages. Accordingly this formation is equivalent to the upper Wyoming of Eldridge. In the Arkansas valley the Red beds have been designated the Fountain formation by Cross and Gilbert and the Badito formation by Hills. From my own investigations I have come to the conclusion that the Fountain formation is the southern extension of the lower Wyoming of Eldridge, for both have characteristics representing the same conditions of sedimentation and with identical stratigraphic relations, some of which I find to be more important than heretofore recognized. The continuity of the outcrops is somewhat obscured by overlap of younger formations in the Arkansas-Platte divide and the various protuberances of old crystalline rocks, but sufficiently significant characteristics and stratigraphic relations continue throughout.

In the Chugwater formation or upper Wyoming in northern Colorado I have found that the Minnekahta limestone almost certainly is represented, and underlying the formation there is a southern extension of the Tensleep sandstone, constituting the top of the lower Wyoming, and traceable at least as far south as Colorado Springs. The upper "Red Bed" series (upper Wyoming) is believed not to be present in the Arkansas valley, but apparently it reappears in southeastern Colorado, between the Morrison formation and the coarser grained red sandstones believed to represent the Fountain formation.

The age of this upper series of Red beds is not definitely known. It usually has been regarded as Triassic for the reason that some known Triassic beds west of the Rocky mountains consist of similar rocks. In later reports the Hayden Survey classified the lower Wyoming beds as Triassic and the upper Wyoming, together with the overlying Morrison, as Jurassic. From fossils found in the Minnekahta limestone in the Black Hills region, a horizon which appears to be continuous through the lower portion of the upper Wyoming beds in Colorado, it is believed that at least the lower third of these beds is Permian; but even if this is the case, the upper portion may be Triassic and represent either all or a part of that period. At their top there is an unconformity which may represent Triassic time together with the Jurassic time, as Jurassic beds are absent to the southward. In the region in which the upper Wyoming beds appear to be absent, southward from the Colorado Springs vicinity, this unconformity at the base of the Morrison comprises all Permian, Triassic, and Jurassic times. Some features of the Red beds along the Rocky Mountain front range are as follows:

Near the Wyoming state line the lower sedimentary rocks consist largely of limestones, which extend south from Wyoming, overlain by fine grained, gypsiferous red sandy shales (Chugwater formation), which are capped unconformably by the Sundance formation (marine Jurassic). These limestones give place rapidly to coarse sandstones, mainly of red color, which extend for many miles south as the basal member of the sedimentary series. At the top of these coarse beds there is always, in northern Colorado, a body of finer grained, regularly bedded sandstone from 50 to 200 feet thick, varying in color from gray to red, which appears to be an extension of the Tensleep sandstone.

The most northern exposures which I examined in Colorado were in Owl canyon, a small branch of the Cache la Poudre drainage, followed by the old main road from Denver to Laramie. The section of the Red beds in this canyon, 17 miles northwest of Fort Collins, Colorado, is as follows:

	Feet
Gray shale and buff sandstone with Jurassic fossils	
Massive pale red sandstone, partly cross bedded	40 +
Red, sandy shales with gypsum at top and thin layers of limestone near bottom	200 +
Gray limestone, in part thin bedded	5
Red sandy shales with several beds of gypsum near bottom	120
Gray cross-bedded sandstone	15
Red sandy shales with two thin layers of limestone	150 ±
Pink sandstone, mostly fine grained, regular bedded	50
Fine grained, light gray limestone	20
Reddish sandstone	25
Fine grained, moderately light gray limestone	15
Reddish to buff sandstone	30
Limestone	6
Coarse red sandstone with red shale	150 +
Coarse reddish and gray conglomerate	100 ±
Granite	

The massive reddish sandstone at the top of the Red beds in this section is a feature which extends southward to beyond South Platte river. It is overlain unconformably by the marine Jurassic at the north and by the Morrison at the south. The local bed of coarse sandstone in the Red beds is an unusual feature. The prominent limestone horizon is believed to represent the Minnekahta limestone of the region north. The 50-foot bed of pink sandstone at the base of the red shales is the member previously alluded to as probably representing the Tensleep horizon. The underlying series of Red beds contain the southern extension of the upper Carboniferous (Pennsylvanian) limestones which were traced southward to beyond Belleview, where they gradually thin out. In another section measured a short distance northwest of La Porte similar features were found. The supposed representative of the Tensleep sandstone is prominent. It is overlain by about 150 feet of soft, red shale, at the top of which there is a series of limestones 30 feet thick· the latter almost precisely similar in aspect and relations to the Minnekahta limestone in the Black hills and at the north end of the Laramie mountains. Next above there are several hundred feet of typical red sandy shales of the upper Chugwater, surmounted by 60 feet of the pinkish red, massive sandstone constituting the top of the formation. In their extension southward the lower Red beds vary greatly in thickness, for they lie on an irregular surface of granite and higher beds overlap lower ones at various horizons. On Little Thompson creek the entire Red bed series has a thickness of about 1,100 feet, of which the upper 350 are regarded as Chugwater (upper Wyoming), having near its base a thin bed of limestone as in the section northward.

There are extensive exposures of the Red beds at Lyons clearly illustrating the stratigraphy. At the base, lying on the granite, are several hundred feet of coarse arkosic red sandstones with some gray mottlings and gray layers. These are capped by 80 feet or more of fine, even grained, pale reddish sandstone, in part thin bedded, which is extensively quarried. It is believed to represent the Tensleep sandstone of the Bighorn region, and is overlain by the usual soft, red, sandy shales typical of the Chugwater formation (upper Wyoming) in the following succession:

Section of Chugwater Formation at Lyons, Colorado

	Feet
Red and green "joint clays" (Morrison)	
Talus	25
Buff and yellowish buff sandstone	30
Dirty red sandstone	30
Red sandy shales	200±
Limestone, thin bedded	15
Red shales or sandstone	80

The thin bedded limestone is very similar to the Minnekahta limestone of the Black hills and central eastern Wyoming. It yielded a few poorly preserved fossils, which unfortunately afforded no decisive evidence as to the age of the beds. They comprised a small gasteropod, supposed to be Natica or Naticopsis, and some small, indeterminate pelecypods, which may be either Triassic or Carboniferous.

In the steep dipping beds west of Boulder a thin bed of similar limestone occurs 70 feet above the top sandstone (Tensleep) of the Lower Wyoming series, from which it is separated by the usual series of bright red sandy shales. It is overlain by gypsiferous red beds.

In the monograph on the Denver region the Red beds are described in considerable detail in their extension from the vicinity of Boulder to south of Deer creek under the terms upper Wyoming and lower Wyoming, the latter lying directly on an irregular surface of granite, as in the region northward. The thickness of the lower Wyoming is found to be exceedingly variable, ranging from 200 to 2,400 feet, while the upper Wyoming varies from 400 to 600 feet, excepting for a short distance near Boulder and Golden, where it thins out entirely. The variations in thickness of the lower Wyoming are due mainly to the inequalities of the granite floor on which it lies, the thicker portions lying in deep basins and the thinner portions being where there is overlap of the higher beds on the slopes of these basins. At the granite contacts at all horizons there are usually coarse cross-bedded sandstones and conglomerates.

Succeeding the basal deposit there is a series of massive, cross-bedded sandstones and grits, with small local bodies of sandy shale. The normal thickness of this series is about 1,200 feet, and its color varies from prevailing red to gray, the finer grained beds being, as a rule, the most highly colored. This bed is shown in foreground of figure 1, plate 32. Toward the upper part of the lower Wyoming there is a transitional zone of lighter red and more quartzose sandstones, which is terminated by a characteristic member of heavily bedded white sandstone from 200 to 400 feet thick, designated the "Creamy sandstone." This member usually forms a well marked ridge 50 to 100 feet high along the middle of the valley of Red beds. Two small bands of dark brown quartzose limestone from 2 to 8 feet thick are present, the lower bed being near the base.

The upper Wyoming division consists mainly of red, sandy shales, such as are typical of the "Red beds" of the region north. "Limestone layers occur within 75 feet of the base, usually 3 or 4 beds of it from 6 to 18 inches thick in the lower 15 feet, and 50 feet higher up a bed 5 feet thick, with red, sandy shale intervening. The upper bed is overlain by a bed of thin, wafer-like layers of white limestone and red mud, in all 5 or 10 feet. The principal members above the limestones are red, sandy shales, with the amount of sand increasing gradually in the higher beds." Thin sandstone layers occur, and occasionally a red sandstone bed becomes prominent. "Higher up, or from 150 to 200 feet below the top of the formation, the strata become more clayey, and present a variety of tints—gray, yellow, green, pink, and lilac—while gypsum and brown earthy limestones are common. Gypsum occurs in small, lens-shaped deposits, mainly in connection with limestones."

The top of the upper Wyoming beds is marked by a sandstone 15 to 25 feet thick, varying from compact and massive to thin bedded and friable, of which the lower 8 feet is usually brown, the middle 10 to 15 feet pink, and the upper 4 feet brown, all fine, delicately cross-bedded, and ripple-marked. This stratum is very distinct, especially at its unconformable contact with the overlying Morrison, which "is somewhat undulating." A typical section of the Wyoming formations at Morrison, Colorado, is as follows:

Upper Division

	Feet
Sandstone, fine-grained, often massive, pink and brown; persistent..	15 to 25
Clays, bright-colored, gray, yellow, green, pink, and lilac; gypsiferous and calcareous, especially at 40 feet below their summit.......	125 to 175
Clays more arenaceous than above; transitional in color, from grays above to prevailing brick reds below...........................	150 to 200
Sandstone and shale, alternating; brick red to pink; white dots; sandstones prominent..................................	50
Sandstones and shales....................................	60
Shales, sandy and argillaceous, brick red, carrying narrow bands (3 to 6 feet) of white crystalline limestone...........................	75

Lower Division

"Creamy sandstone;" quartzose; conglomeratic at base; two sandy limestone bands in lower part; round ferruginous concretions near top; forms prominent outcrop in valley between Archean and Dakota (average, 250 feet).....................................	200 to 400
Red beds; conglomerates, sandstones, and shales, the last of minimum development; color, red; outcrops, lofty spires and pinnacles and towering masses of irregular shape................................	270 to 2,000

I visited Morrison in 1901 in order to compare its section with those which I had been studying in the Black hills and Bighorns. I found the "creamy sandstone" series strongly suggestive of the Tensleep sandstone of the Bighorns and the top sandstones of the Minnelusa of the Black hills. The overlying red shales begin abruptly and they are very closely similar to the Opeche in aspect and relations. The limestone bands have the character of the Minnekahta limestone, especially the upper bed, which is 5 feet thick and lies, as stated by Eldridge, 70 feet above the "creamy limestone," a position similar to that of the Minnekahta limestone in the northern part of the Laramie range, in eastern Wyoming and elsewhere north and west. A careful search for fossils yielded a few indistinct forms similar in appearance to the Bakewellia of the Minnekahta limestones of the Black hills. The overlying red, sandy shales, with gypsum, are very like the Spearfish formation of the region north. The pinkish sandstone at the top, underlying the Morrison, is the same as the top member at other localities north.

Peale* and Marvine† have described some features of the Red Bed exposures on South Platte river, at the mouth of the canyon. The basal beds lying on the granite consist of coarse, white and red, mottled sandstones, overlain by finer grained red sandstones, in all 1,500 to 2,000 feet thick, capped by 600 feet of white sandstone corresponding to the "creamy sandstone" of Eldridge (Tensleep sandstone). This member has reddish bands 4 to 6 feet thick, separating the white portions into bands 20 to 30 feet thick, in part conglomeratic. The upper Wyoming division is not well exposed, but it is reported to contain a layer of compact, red limestone near its base and thin limestones and limy shales higher up.

A similar section was given for Willow creek by Doctor Peale, and Eldridge‡ has given some details regarding the succession of limestones in the upper Wyoming beds in that vicinity. There are four thin layers of white limestone, one lying immediately on the "creamy sandstones" and the others 30, 60, and 70 feet above.

For Perry park (formerly Pleasant park), on Beaver creek, there are sections by Doctor Peale§ and Mr W. T. Lee.‖ Doctor Peale's section of the Red beds, etcetera, at Pleasant (Perry) park, Colorado, is as follows:

	Feet
Thin limestones (at base of Morrison, probably)	
Gypsum	81
Slopes with few outcrops of thin limestone beds, four in all, averaging 4 feet thick (probably in red shales)	461
Mottled yellow and red sandstones, very light colored above, mottled reddish below,	1,500
Massive red sandstones	
Slope apparently underlain by red sandstones	
Coarse white sandstone, loosely cemented in upper part, has bands of red sandstone varying from 1 to 3 feet thick	80
Small outcrop of limestone, with chert pebbles and fossils (Terebratula and Spiriferina) overlain by purplish sandstone and gray sandstone	6
Irregular bed of limestone, with pebbles of greenish chert and limestone	3
Red calcareous sandstone, very hard, and with cross-bedding layers 1 inch thick	3

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*Seventh Ann. Rept. U. S. Geol. and Geog. Survey of the Territories for 1873, by F. V. Hayden, p. 195.

† Ibid., pl. opposite p. 93.

‡ Geology of the Denver Basin. Monograph U. S. Geol. Survey, vol. xxvii, 1896.

§ Seventh Ann. Rept. U. S. Geol. and Geog. Survey of the Territories for 1873, by F. V. Hayden, pp. 197–199, pl. 2.

‖ Am. Geologist, vol. 29, 1902. pp. 97–98.

	Feet
Compact red sandstone in 1-foot layers, veined with calcite	15
Dark purplish cherty limestones	3
Red limy sandstone	4
Very coarse white sandstone lying on granite	80

The 80-foot bed of coarse loose sandstone in this section is regarded as the same as the basal member in the Platte Canyon section, where the underlying 114 feet of beds of the Perry Park section are thought to be absent. The upper "Red beds" underlying the 81 feet of gypsum at the top give a thickness of 542 feet for the upper Wyoming of Eldridge, which I think is an excessive estimate. The lower limestone in this top series strongly resembles the Minnekahta limestone and has the same stratigraphic relation in lying near the base of the Chugwater formation (upper Wyoming) and being separated from the gray sandstone at the top of the lower Wyoming by red shales, as in the sections north. The heavy gypsum bed at the top of the formation extends for several miles, but varies greatly in thickness. From the limestones near the base of the Perry Park section Mr Willis T. Lee obtained the Mississippian fossils described on a previous page.

The Red beds are extensively exposed in the Garden of the Gods and adjacent regions about Manitou and Colorado Springs, where they are underlain by Millsap (Mississippian) limestone. The division into upper and lower Wyoming is distinct, the latter having a thickness of a thousand feet or more, and the former being not over 90 feet, or very much less than in the region northward. The lower Wyoming beds present their usual features of coarse grained, massive, cross-bedded sandstones, predominately of red color. They give rise to the picturesque features of the Garden of the Gods, shown in plate 33, the "gateway" marking the outcrop of the uppermost hard, red stratum. Next above there are some softer, striped red and gray beds about 100 feet thick, not well exposed at the gateway, and then the bed of white sandstone which outcrops so conspicuously in the low but sharp ridge just east. This bed is about 100 feet thick, moderately fine grained, but massive and cross-bedded, and almost surely represents, together with the underlying softer sandstone, the "creamy sandstone" at the top of the lower Wyoming of Eldridge (the Tensleep sandstone of the Wyoming region). In the vicinity of the Garden of the Gods it is similarly succeeded abruptly by soft red shales, with thin limestones near the base and typical gypsum deposits above, extending to the base of the Morrison shale. I think there can be no question as to the equivalency of this upper series to the upper Wyoming of Eldridge or the Chugwater formation. The following section of upper Red beds between the gateway of the Garden of the

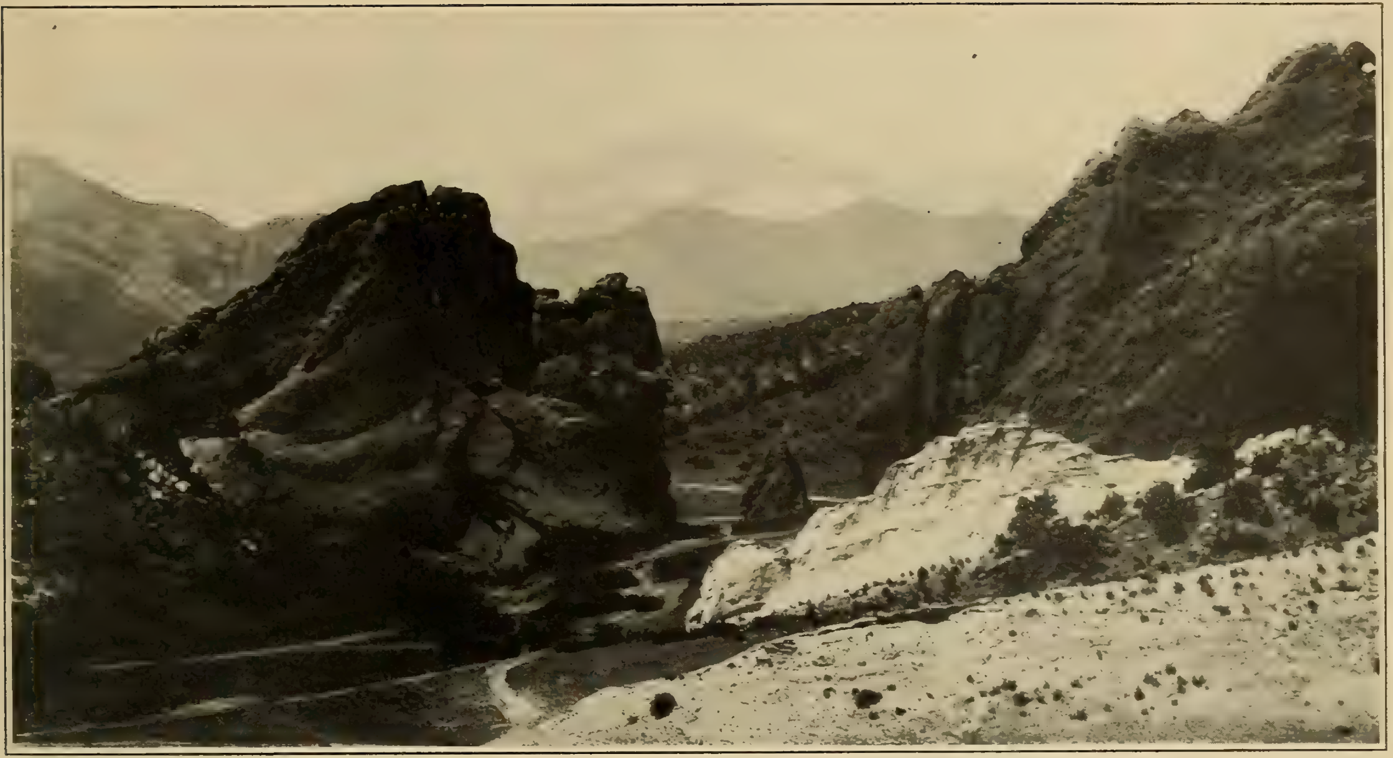

Figure 1.—Gateway of Garden of the Gods, Colorado Springs, Colorado

Pikes Peak in western distance; "gateway" is of lower Wyoming red grits; white ledge is "creamy sandstone" (Tensleep) at top of lower Wyoming; gypsum bed at top of upper Wyoming in foreground

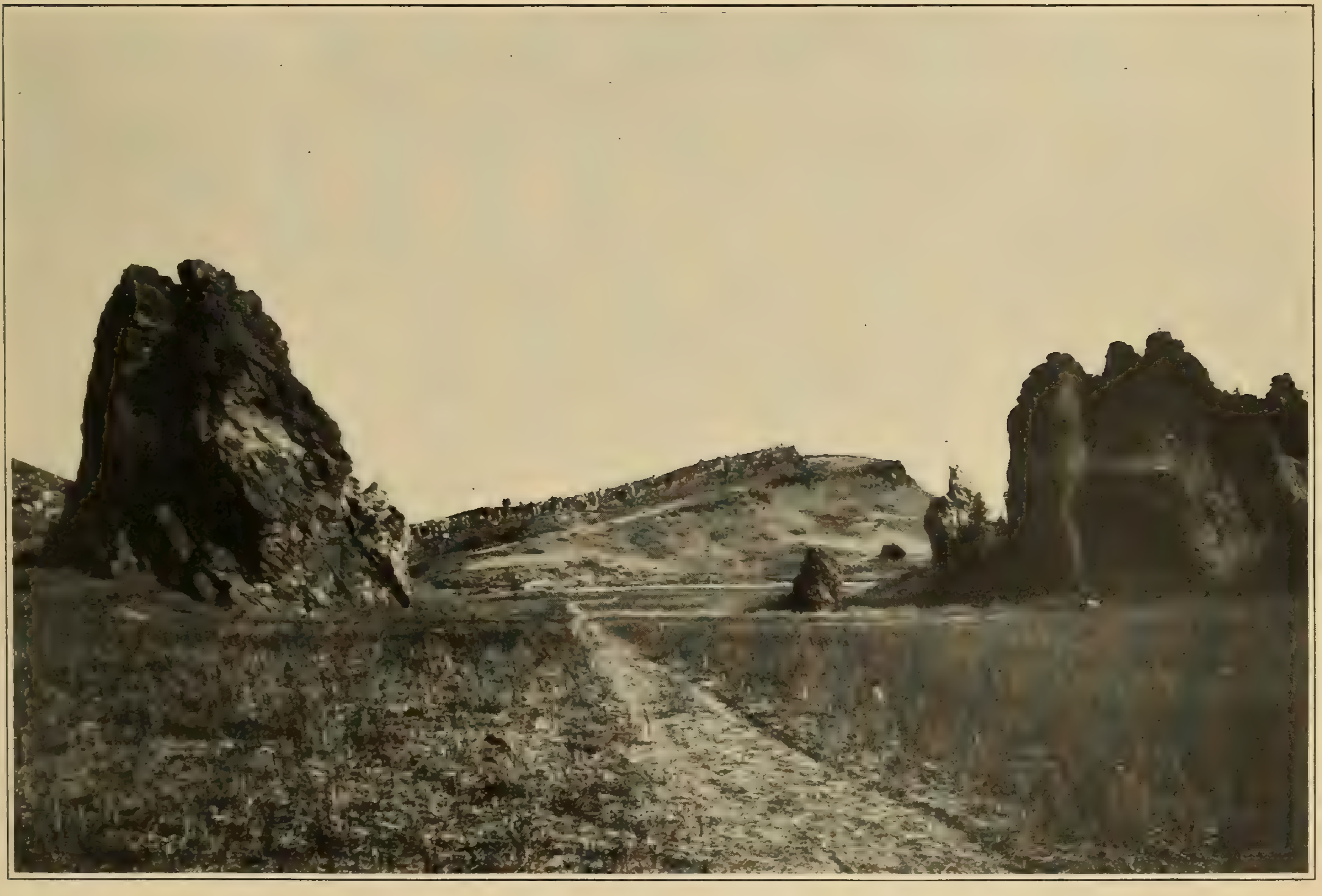

Figure 2.—Gateway of Perry Park, south of Denver, Colorado

Vertical beds of lower Wyoming red grits in foreground; two sandstones of "Dakota" in distance, surmounting slopes of Morrison shales and gypsiferous red beds

GATEWAY OF GARDEN OF THE GODS AND OF PERRY PARK

Gods and Glen Eyrie, Colorado, was measured a short distance north of the gateway:

		Feet	
Morrison	Clays		
Chugwater formation or upper Wyoming beds.	Gypsum	30	
	Red shales, with thin gypsum bed	30	
	Limestone	3	(Minnekahta)
	Red shales, with thin limestones	22	
	Limestone, purple, thin layers	1	
	Soft red shale and sandstone	55	
Top of lower Wyoming beds.	Massive white sandstone		Tensleep sandstone

To the south the two series of Red beds preserve the same general features to the overlap at the foot of Cheyenne mountain, but there are local variations. Southwest of Fountain, where the beds are again exposed, the upper Wyoming appears to be present for a few miles, and then thins out, giving place to coarse grained red beds of lower Wyoming character, directly overlain by Morrison beds. This coarse series, or the entire Red Bed succession of this region, has been designated the Fountain formation by Cross and Gilbert. The typical Fountain deposits are precisely equivalent to the lower, coarse grained Red beds in the Garden of the Gods region, and, on special investigation of this point in the field, I could find no suggestion but that they both represent the same period of deposition. They are alike in character, representing the same conditions as to origin; they are similarly underlain unconformably by remnants of Millsap limestone, and there is not the slightest evidence that one overlaps the other.

The Fountain formation in the region extending from southwest of Fountain to Canyon City consists mainly of coarse grained, crumbling arkosic sandstone in massive beds, usually cross-bedded. Many conglomeratic streaks occur, and at various horizons there are layers of finer grained material. The beds are prominently reddish, but some are gray and others are mottled gray and red. The finer grained materials are nearly all of a bright brownish red color. The thickness is estimated at 1,000 feet, but it varies considerably. For the greater part of their course, the deposits to which the name has been applied are separated from the granites and gneiss by limestones of Ordovician age, but in places they overlap the crystalline rocks, and at some localities the underlying limestones are faulted out. In the vicinity of Canyon City and at a small locality on Cripple creek, at the head of Garden park, the underlying Millsap limestone appears.

In the region southwest of Pueblo the thickness of the Fountain formation, as measured by Mr Gilbert, is 2,100 feet, which includes practically all of the formation, but it thins out to the southward, and is absent for some distance along the foot of Greenhorn mountain. At the south end of this mountain appears a similar series of rocks which Mr R. C. Hills named the Badito formation. It comprises an upper member about 100 feet thick, generally massive or thick bedded, but sometimes shaly on the weathered surface and corresponding to a part of the Fountain formation. The lower half consists of about the same thickness of very coarse conglomerates of brownish red color. This series appears again in the Culebra range, where it expands to a great thickness and includes limestones which appear near La Veta pass and extend southward into New Mexico. This area was described in considerable detail by Endlich, of the Hayden survey, who mapped the lower portion of the series as "Lower Carboniferous," and several thousand feet of overlying Mesozoic and Eocene beds as Upper Carboniferous. In 1902 Mr Willis T. Lee* collected fossils in this district, mostly from the lower beds of the series not far above the granite. They were identified by Dr Stuart Weller and found to be Upper Carboniferous. Forty-six species were represented. The rocks consist of a variable alternation of coarse gray to red sandstones, shale, and limestones.

A small collection of Upper Carboniferous fossils was also obtained from the western slope of La Veta pass, 5 miles above Placer, in a succession consisting of sandstones, limestones, shales, and conglomerates similar to those above described.

It was found by Mr Lee that the Millsap and underlying limestones are not present in the Culebra range, although possibly there may be small outliers of them in portions of the range which he did not visit. The strata overlying the section given above consist of several thousand feet of red and gray sandstones, mostly coarse, extending to the base of the Morrison formation and representing the Fountain series.

SUNDANCE FORMATION

The Sundance formation extends only a few miles into Colorado from the northward, finally ending by thinning out. Doctor Hayden † found fossils, "*Ostrea* and fragments of *Pentacrinus asteristicus*, on Box Elder creek, in yellow sandstones and clays," with scattered layers or nodules of limestone. He suggested that the limestone sometimes found at the base of the Morrison formation may be a representative of the marine Jurassic, a suggestion based on its similarity in character and relations to a limestone on the Laramie plains, which contains *Apiocrinites*. As similar limestones exist in typical Morrison beds northward, where the marine Jurassic is represented, I feel certain that all those in the Front range are of Morrison age.

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* Carboniferous of the Sangre de Cristo Range. Jour. Geol., vol. 10, 1902, pp. 393-396.

† F. V. Hayden: Third Ann. Rept. U. S. Geol. and Geog. Survey Terr. (for 1869), p. 119.

MORRISON FORMATION

This formation extends along the entire Rocky Mountain front through Colorado, outcrops frequently, and presents very characteristic features. At a very few localities it is cut off by faults or locally buried under overlaps of younger formations. It is also exposed in some of the canyons eastward, notably in the deeper ones of eastern Las Animas county and in the Two Butte uplift. Its general character is nearly uniform throughout, a series of light colored, massive clays, "joint clays," with thin beds of limestone and sandstone of fresh water origin containing bones of saurians of the so-called "Atlantosaurus" fauna. Its thickness averages less than 200 feet in most cases. It presents frequent and rapid variations in the local succession of beds, but the predominance of joint clays of chalky aspect and the occurrence of maroon and purplish layers among them are characteristic features. The name Morrison was given by Eldridge from the town of Morrison, where the formation is extensively developed. South of the end of the marine Jurassic deposits (Sundance formation) the Morrison beds lie unconformably on the Chugwater formation for many miles, and southwest of Colorado Springs overlap the Red beds of the Fountain and Badito formations. In eastern Las Animas county they lie on a bed of gypsum. Mr W. T. Lee has traced them into western Oklahoma and found that they either merge into or take the place of the marine beds of the upper formations of the Comanche group in the Lower Cretaceous, a relation which I have found also near Two buttes, on Butte creek, in Prowers county, Colorado. The saurian remains which have been obtained so abundantly from the Morrison beds west of Denver and north of Canyon City are regarded as latest Jurassic by some paleontologists and earliest Cretaceous by others, but from the stratigraphic relations of the formation to the Comanche it is preferable to class it in the Lower Cretaceous.

The basal unconformity is one of widespread planation, with local shallow channeling but no perceptible discordance of dips. The following section of the Morrison formation was measured northwest of Laporte, Colorado:

		Feet
"Dakota"	Coarse sandstone, with conglomerate at base	
Morrison	Gray massive shales, with thin limestone bed about 20 feet below top.	80
	Limestone, gray, with algæ	6
	Sandy shale, reddish to buff, partly massive	20
	Pinkish and buff sandstones at top of Red beds	60

The basal, reddish sandy member of the Morrison at this place is an unusual feature in Colorado. East of Lyons there are excellent exposures of the Morrison exhibiting the very unusual thickness of about 420 feet, consisting of the following beds:

		Feet
"Dakota"	Sandstone, hard, massive, buff	
Morrison	Olive green massive shale, with some sandstone layers	150
	Light grayish green massive shale	30
	Soft to hard gray sandstone, fine grained	15
	Red, maroon, and green massive shale	150±
	Massive buff sandstone, moderately fine	10
	Grayish green to maroon massive shale, with thin layers of fine grained sandstone	40
	Covered	25
Upper Wyoming	Soft buff sandstone	30

The typical Morrison formation in the region west of Denver has been defined by Eldridge* as consisting of fresh water marls having an average thickness of 200 feet, the amount varying somewhat. Its upper limit is sharply defined by the "Dakota" sandstone, while the brown and pink sandstone, regarded as the top member of the "upper Wyoming," clearly marks its lower limit.

Mr Eldridge's description of the formation is as follows:

> "The marls are green, drab, or gray and carry in the lower two-thirds numerous lenticular bodies of limestone of a characteristic drab color and a texture compact and even throughout. A small but persistent band of sandstone and limestone in thin alternating layers occurs about 20 feet above the base. In some places the arenaceous elements largely predominate, and near Mount Vernon, 3 miles north of Morrison, and in the vicinity of Van Bibber creek there are at about this horizon from 10 to 15 feet of dull gray or yellowish sandstones."
>
> "The upper one-third of the formation is generally a succession of sandstones and marls, of which the former predominate." "The most important sandstone occurs just above the lower clays, is very persistent, and from contained saurian remains has been called the saurian sandstone. It varies in thickness between 5 and 35 feet, and in its distance below the Dakota from 10 to 125 feet, although more generally it lies 50 to 80 feet below." "The sandstone is locally divided into several layers by thin intercalations of drab clay. In the vicinity of Turkey creek these clays reach the unusual thickness of 20 to 30 feet, the sandstones aggregating about 20 feet." "The shales overlying this sandstone are similar to those comprising the bulk of the formation, but carry through them a number of minor sandstones and occasionally one or two strata of limestone."
>
> "The cause of the variation in the thickness of the upper half of the formation could not be determined from conditions existing in the Denver field, but an oft-suggested unconformity at the base of the Dakota may be the explanation."

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* Monograph U. S. Geol. Survey, vol. 27, 1896, pp. 61–62.

The formation is exposed at intervals from South Platte river to Colorado City. A short distance north of the Gateway to the Garden of the Gods its thickness is 130 feet, and the basal beds lying on the thick deposit of gypsum at the top of the Chugwater formation consist of ashy gray massive shales with several thin limestone layers and a few streaks of clay pebbles. These grade up into typical pale greenish and maroon massive clays with a few thin layers of fine grained light colored sandstone abruptly overlain by coarse grained buff colored "Dakota" sandstone. At Colorado City the Morrison beds are exposed in the railroad cut. but only in part, the top and bottom members being covered by talus. The dips are nearly or quite vertical. To the west are 55 feet of pale greenish gray sandy shale, mostly massive, with thin layers which are overlain (to the east) by a 15-foot bed of soft pale greenish gray sandstone. The formation is cut off by the pre-Cambrian rocks south of Colorado City, but appears again in the embayment north and northeast of Canyon City. In Garden park on Oil creek it has a thickness of about 350 feet, according to Cross,* and consists mainly of greenish, pinkish, or gray shales or marls with sandstone layers at various horizons. It usually lies on the Fountain formation, but overlaps locally onto the granite. In this region the formation has yielded large numbers of dinosaur remains. Hatcher† has recently described the formation and its relations in the Garden Park area. He estimates the thickness at 450 feet, placing the upper limit higher than Cross, so as to include some sandstones and shales containing dinosaur remains. The bones have been obtained in largest number from a thick sandstone about 150 feet above the base of the formation, but some occur 30 feet below this stratum, and others have been found at various horizons above, both in shale and sandstones. Just below the main bone-bearing sandstone bed there is a layer of clay with thin limestone beds containing numerous fresh water gasteropods, and in a marly layer, at a somewhat lower horizon, occur abundant remains of Unios. These fossil shells have been described by C. A. White, who classes them as Jurassic because they occur with supposed Jurassic dinosaurs, but he states that otherwise they might be regarded as much younger, so that they throw no light on the age of the beds. Hatcher reports the discovery of an Inoceramus at the Garden Park locality.

South of Canyon City these beds do not reappear again until in the vicinity of Beulah, southwest of Pueblo, where they extend for a few miles along the foot of the mountains, as described by G. K. Gilbert.* North of Beulah for several miles the " Dakota " sandstone lies directly on the Fountain formation, but probably the Morrison beds formerly covered the region and were removed by pre-Dakota erosion, a very unusual relation. The Morrison beds south of Beulah, according to Mr Gilbert, consist chiefly of red shale with a few layers of hard, red sandstone beds about 70 feet thick. They are faulted against the gneiss and also overlap onto that rock for a portion of their course. The formation appears again for 5 miles at the south end of the Greenhorn mountains, lying partly on gneiss and partly on the Red beds. Its thickness here, according to Hills,† is 270 feet, the lower portion consisting of about 60 feet of soft, white sandstone, conglomeratic at base. The middle portion is a series of pinkish and greenish, massive clays, and the upper beds are variegated shales and clays, alternating with bands of fine grained limestone, often containing vermilion colored cherts. Hills states that there is considerable doubt as to the true position of the formation in the time scale and assigns it to the Jurassic provisionally.

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* Whitman Cross,: Description of the Pike's Peak district. Geologic Atlas U. S., folio 7, U. S. Geol. Survey, 1894, p. 2.

† J. B. Hatcher: Annals of Carnegie Museum, vol. 1, 1901, pp. 327-341.

"*DAKOTA*" *SANDSTONE*

Under this heading there will be described the entire sandstone series overlying the Morrison formation, a series which always has been known as the " Dakota sandstone." It generally consists of two bodies of sandstone, each a hundred feet or more in thickness, separated by a deposit of clay or shale 10 to 15 feet thick. The clay and the top sandstone have yielded abundant plant remains of the Dakota flora (upper Cretaceous), but there is less conclusive paleontologic evidence as to the age of the basal sandstone series. The tripartite succession strongly suggests the Dakota sandstone, Fuson clay, and Lakota sandstone of the Black hills.

The " Dakota " sandstone is remarkably uniform in character throughout eastern Colorado. The rocks are mostly hard and massive, giving rise to a well marked hogback range along the foothills and plateaus, and to steep walled canyons in the southeastern part of the state. The predominating color is light buff. Cross-bedding is almost general and conglomeratic streaks are frequent, especially at or near the base of the lower sandstone. The contact with Morrison beds is abrupt and often presents evidence of unconformity by erosion, but no more than is generally found wherever a coarse sand has been deposited on clay. There is often a very rapid change to Benton deposits, but in most areas there are a few feet of transition beds consisting of an alternation of shales with thin bedded, brown sandstones. The lower sandstone series is thicker than the upper, often somewhat softer, and it contains shale partings at some localities. The middle shale member appears to be present throughout, but generally it is covered by talus. In the region west of Denver the "Dakota" formation is described by Eldridge as having a thickness of 225 feet, consisting of two or three nearly equal benches of massive sandstone separated by thin bodies of clay, a characteristic conglomerate at the base and a zone of hard, white, slaty shales 10 to 30 feet thick at the top, transitional to the Benton. Fossil plants, mainly leaves of the deciduous trees, and enormous fucoids are stated to occur from base to summit. The sandstones vary from cross-bedded to slabby and often some layers are ripple marked. The basal conglomerate varies from almost nothing to 30 feet in thickness and is composed of well rounded pebbles from the size of a pea to a diameter of 1 inch.

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* G. K. Gilbert: Description of the Pueblo district. Geologic Atlas U. S., folio 36, U. S. Geol. Survey, 1897.

† R. C. Hills: Description of the Walsenburg district. Geologic Atlas U. S., folio 68, U. S. Geol. Survey, 1900.

In the Denver region there are generally two beds of clay—one midway in the formation and the other nearer the summit. The thickness of these varies from 2 to 8 feet, and the material is in part a typical fireclay of blue or blue gray color, fine, even grained, and very compact; but in places it has intercalated sandy shales. The "Dakota" formation thins out and disappears for several miles in the vicinity of Golden.

Doctor Peale* gives the following section of "Dakota" sandstone at the mouth of the South Platte canyon, Colorado:

	Feet
Gray and yellow sandstones	70
Shaly sandstones, fossiliferous	12
Fine grained white sandstones	3
Rusty yellow sandstone	245

The total thickness of these members is 330 feet. The fossils referred to were determined by Professor Lesquereux and included a *Proteoides* very near *P. acuta*, H. At Perry (Pleasant) park Doctor Peale measured 213 feet of "Dakota" sandstones, but found its upper and lower contacts obscured by talus. The tripartite succession is plainly shown in figure 2, plate 33. The sandstone appears again for several miles in the Garden of the Gods region, where Doctor Peale reports 257 feet of exposed beds, consisting of 200 feet of massive sandstones above, underlain by a finer grained sandstone in part yellow, containing fragments of *Lingula* and a lignitic layer with vegetal fragments. My own measurement in vertical beds near the Gateway gave considerably less thickness, and the formation was found to consist of two massive beds of sandstone apparently with a thin series of shales between. The great overlap and fault cuts off the formation southwest of Colorado Springs, but it appears again in the Canyon City region, where Cross found a thickness of 300 feet, consisting mainly of pure white or gray sandstone, usually friable, of uniform texture, and having a thin basal conglomerate. The hogback at this place is shown in figure 2, plate 34. Dark shale layers are reported midway in the formation. Fossil leaves are stated to occur in thin shale layers of various horizons, and Hatcher has found saurian remains in the lower portion of the series in this region.

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*F. V. Hayden: U. S. Geol. and Geog. Survey Terr., Seventh Ann. Rept. (for 1873), p. 195.

The "Dakota" sandstone is prominent at the foot of Wet mountain, southwest of Pueblo, where it has been described by Mr Gilbert.* Its greatest measured thickness, near Beulah, is 650 feet, consisting almost entirely of sandstone, but the thickness in other portions of the area is from 300 to 350 feet, and the sandstone contains beds of shale. The basal portion usually is conglomeratic, sharply separated from the Morrison clays or Fountain formation, which it overlaps locally, and at the top there is a transition into the Benton formation.

In the northern portion of Huerfano county and along the foot of the Greenhorn mountain the formation is described by Hills as comprising of 350 feet or more of sandstone, of which the lower two-thirds consists generally of yellowish gray rock of coarse porous texture, with some layers of fine conglomerate, commonly cross-bedded. This lower member is separated from the upper by gray shales, from 100 to 150 feet in thickness, and are light gray and fresh, fine grained, of close texture, and regularly bedded. It lies in part on the Morrison formation, but in places along the mountain front overlaps on the granites and schists. The "Dakota" sandstone is a prominent feature in the foothills between the Spanish peaks and Sangre de Cristo range, where for many miles the sandstone is vertical and rises prominently as a "stone wall" above the adjoining softer beds.

BENTON GROUP

The formations of the Benton group extend across eastern Colorado, outcropping in a narrow zone lying next west of the Niobrara outcrop as far south as the Arkansas valley, down which they extend for some distance, presenting outcrops of greater or less size mainly on the north side of the valley.

The thickness of the group is given as 600 feet at Platte canyon, 590 feet at Deer creek, west of Denver, 500 feet on Turkey creek, 580 feet at Morrison, 400 feet one mile north of Morrison, 440 feet at Ralston creek, 348 feet at Bear canyon, 3½ miles south of the town of Boulder, and about 500 feet at Four-mile canyon. It is about 640 feet east of Lyons.

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* Pueblo folio, cit.

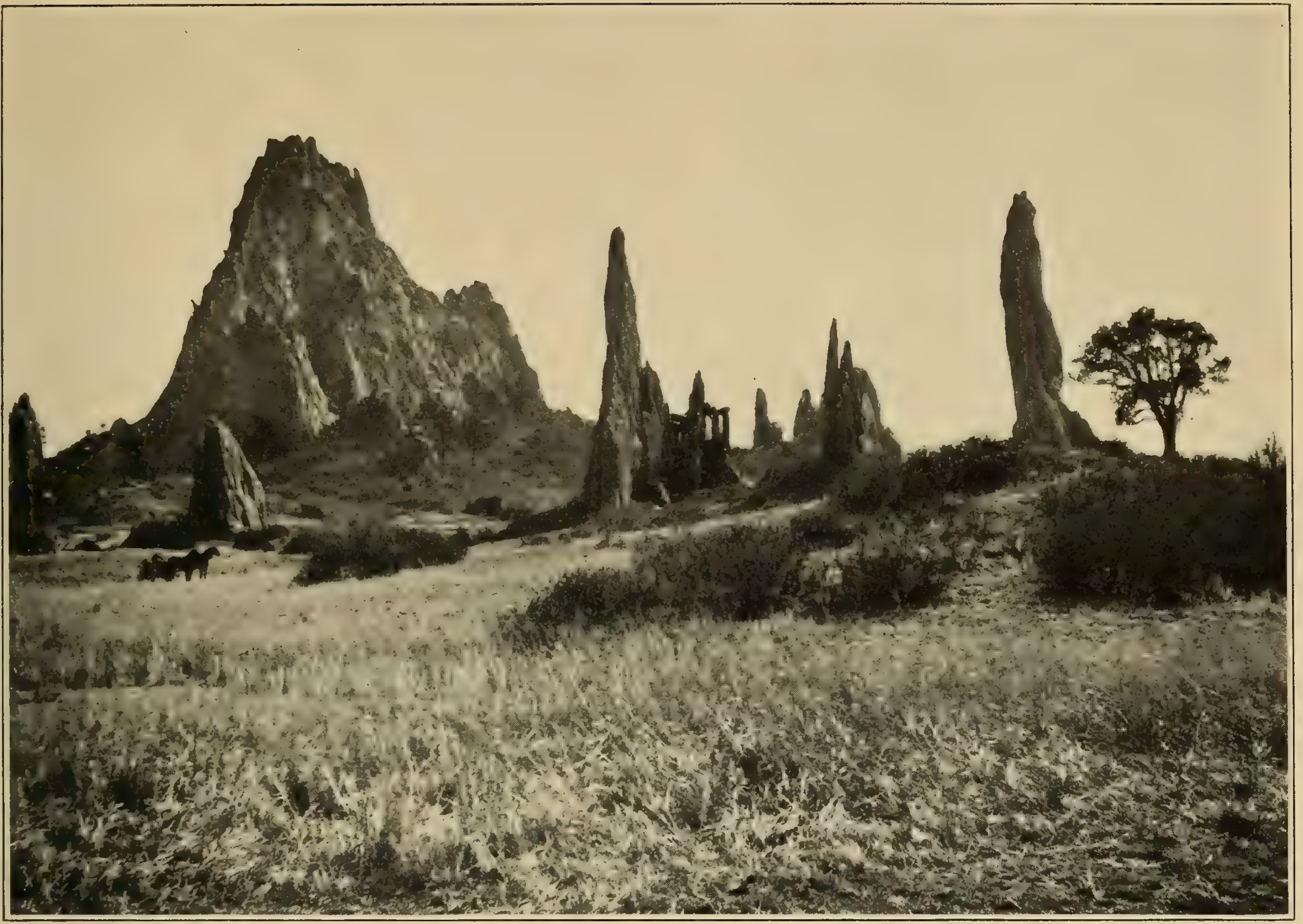

FIGURE 1.—VERTICAL LOWER RED BEDS IN GARDEN OF THE GODS

Shows characteristic erosion due to unequal hardness of the beds, over 1,000 feet thick

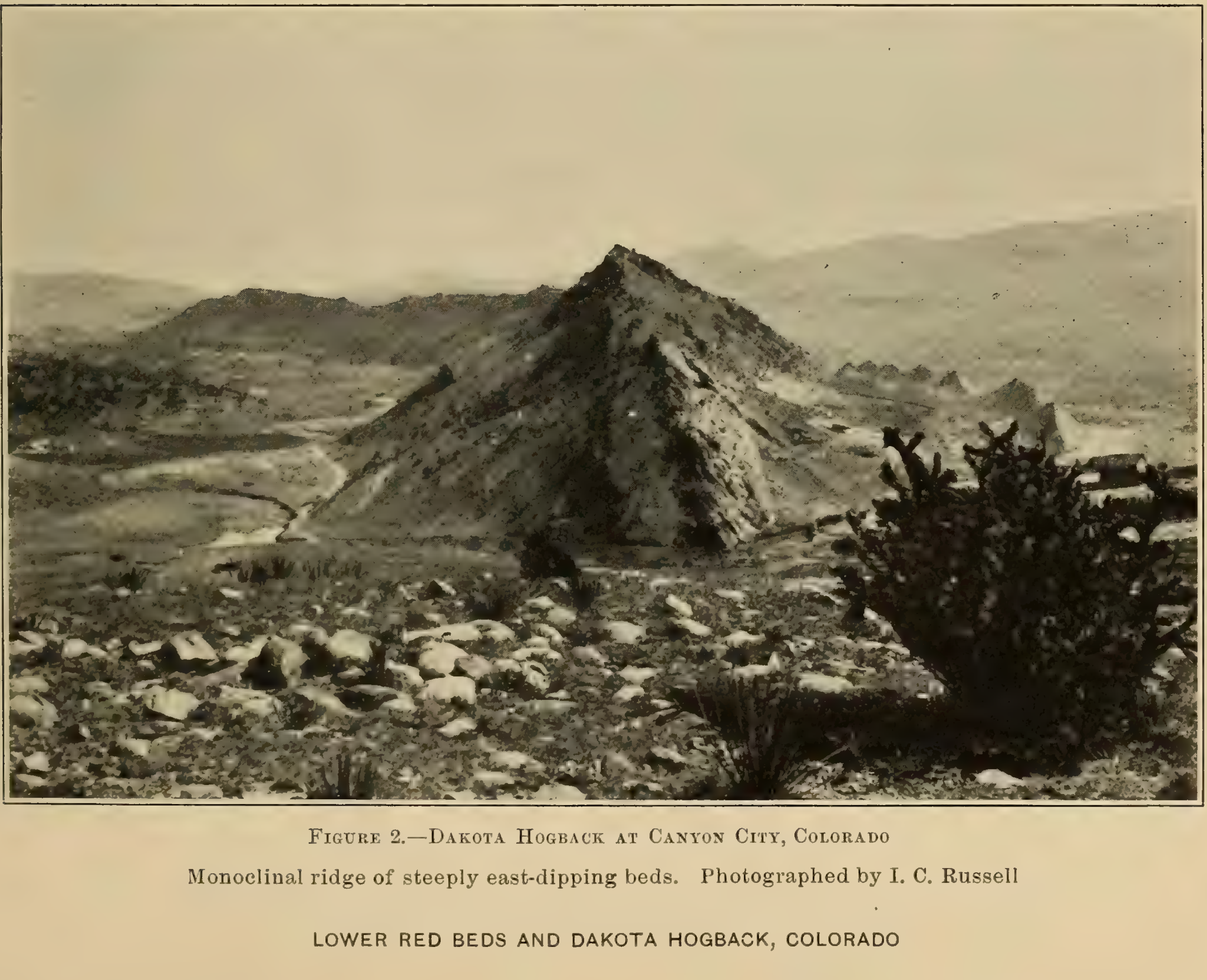

FIGURE 2.—DAKOTA HOGBACK AT CANYON CITY, COLORADO

Monoclinal ridge of steeply east-dipping beds. Photographed by I. C. Russell

LOWER RED BEDS AND DAKOTA HOGBACK, COLORADO

In the Arkansas valley region it varies but little from 410 feet. The three formations which Mr G. K. Gilbert has differentiated as Graneros shale, Greenhorn limestone, and Carlile shale in the Arkansas valley have been found to be easily traceable all along the Front range through Colorado.

GRANEROS SHALE

This formation is a fissile, dark colored shale, generally uniform in composition and usually about 200 feet thick, though the amount increases considerably west of Denver. In this region prominent zones of iron concretions occupy a thickness of from 40 to 50 feet at a horizon about 200 feet above the base of the formation. East of Lyons, on Little Thompson creek, the Graneros formation has a thickness of 525 feet or more, with the following components:

	Feet
Shales, dark above, lighter below	125
Fossiliferous limestone	½
Dark shales	225
Sandstone, partly thin bedded	15
Dark shales, with few thin beds of sandstone	160 +

GREENHORN LIMESTONE

This widespread formation consists of impure shaly limestones 25 to 40 feet thick, in layers from 3 to 12 inches thick, separated by several inches of shale, as shown in figure 1, plate 27. Figure 2 in this plate illustrates the similarity of the formation in the Black Hills region. The deposit is of light gray color when fresh and relatively soft when moist, but it hardens on weathering, usually becoming sufficiently hard to constitute a low but distinct ridge.

The limestone is characterized by containing large numbers of *Inoceramus labiatus*, which occasionally occur in other beds but are extremely abundant at this horizon. The formation outcrops in a wide area in the Arkansas valley in Colorado and Kansas. It is 75 feet thick and rises prominently in the ridge behind the house at the Gateway to the Garden of the Gods and outcrops frequently in the Denver region and northward. East of Lyons it appears between the Dakota and Niobrara ridges with a thickness of 25 feet, consisting of limestone layers 4 to 10 inches thick separated by a few inches of dark shales and filled with *Inoceramus labiatus*. West of La Porte it is 20 feet thick and presents its usual characteristics and fossil.

CARLILE SHALE

This shale in its typical development about Pueblo and along the Arkansas valley is from 175 to 200 feet thick, west of Colorado City it is

240 feet, and east of Lyons 125 feet. It consists mainly of clay of gray color, slightly darker below than above, with more or less sand, especially to the westward along the Rocky Mountain front, where its upper member is usually a gray sandstone 6 to 15 feet thick. East of Pueblo, in the Arkansas valley, the sandstone is replaced by a purple limestone 2 to 3 feet thick, containing fossils of which the most characteristic is the *Prionocyclas wyomingensis*, and about 125 feet lower down there is usually a thin bed of impure limestone containing fossils. Near the top of the formation the shales contain numerous lens-shaped lime concretions, in greater part from 2 to 4 feet in diameter, containing *Prionotropis woolgari*.

NIOBRARA FORMATION

The Niobrara outcrop extends from north to south across central Colorado, a short distance east of the foothills. It has extensive surface outcrops along the Arkansas valley. The upper members consist mostly of impure chalk and calcareous shale, while at the base of the formation there are beds of moderately pure hard limestone or dolomite. The thickness in the Pueblo region and for some distance down the Arkansas valley is 700 feet; but west of Denver and in Kansas it is only about 400 feet, a diminution in thickness to the north and to the east which appears to be gradual. The calcareous shale of the upper portion of the formation has a thickness of about 500 feet in the Pueblo region and half as much in the Denver region. The beds are gray in color when fresh, but on weathering develop a distinctive bright yellow tint. Occasional thin sandy beds occur and many thin masses of limestone filled with *Ostrea congesta.* In the Arkansas valley the formation contains concretions which are often of considerable size. In this valley there is an intermediate member of light gray shales and marls containing a large amount of lime and occasional thin beds of limestone with *Ostrea congesta.* This member is from 100 to 125 feet thick, and it grades downward into a persistent bed of hard limestone, which is the westward continuation of the Fort Hays limestone of Kansas. The thickness of the limestone averages about 50 feet, consisting of beds in greater part from 8 inches to a foot thick, separated by thin layers of gray calcareous shale.

The rock is of light gray color, weathering nearly white on some of the surfaces, and is close textured, fine grained, and moderately resistant. The characteristic fossil of the lower limestone is the *Inoceramus deformis*, usually associated with a greater or less amount of *Ostrea congesta.* Northward in Colorado the formation usually presents three beds of limestone, the lower one the thickest, separated by calcareous shale. At the top is a chalky bed, which weathers to a characteristic bright straw yellow color.

PIERRE SHALE

Nearly all of the Great Plains portion of Colorado north of the Arkansas river is underlain by a sheet of this formation, and it extends along the flanks of the Rocky mountains south from Florence to Trinidad. Its thickness is great, from 4,000 to over 7,000 feet, adjoining the mountains; but it is much less to the east. About Denver and to the south and north it is overlain by Laramie and still later formations. Its character is remarkably uniform throughout, a dark colored clay or shale, with local slight variations in color and stratigraphic components.

Lime concretions of various sizes are of frequent occurrence, and some local beds of sandstone are included, which in the vicinity of Florence and Boulder yield petroleum in considerable amount. The lime concretions begin to be abundant above the first 400 or 500 feet of basal members of the formation and continue to its top. In the Pueblo region these concretions are particularly abundant in a zone about 600 feet thick, lying from 400 to 500 feet above the base of the formation, and carry fossils typical of the Pierre formation. Above this zone the shales are paler in color and finer grained and concretions are abundant, generally larger, and much more fossiliferous than those occurring lower down. The fossils are often well preserved, showing the actual shells with much of their original pearly luster. *Baculites compressus* and large *Inoceramus sagensis* abound. In this zone to the south there are found occasional large limestone concretions which give rise to tepee buttes.* The characteristic fossil in the limestone is a small shell known as *Lucina occidentalis*, which is about an inch in width. Other Pierre fossils also occur in the limestone. Above the zone of shales containing the limestone lenses of tepee buttes there are several hundred feet of dark shales to the top. In the Florence basin the formation contains many thin, sandy beds carrying the oil, and its thickness is at least 4,000 feet. To the south about Trinidad it is from 1,200 to 1,300 feet, according to R. C. Hills. West of the Denver basin the Pierre shale appears to have a thickness of 7,700 feet, which is more than observed anywhere else in the Great Plains region. Here the formation contains local beds of limestone which are thin and a local bed of sandstone which varies from 100 to 350 feet thick. The sandstone is a soft, friable, yellowish gray rock composed of quartz sand and more or less clay intermixed and intercalated. It is about 2,500 feet above the base of the formation.

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*Described by G. K. Gilbert: Seventeenth Ann. Rept. U. S. Geol. Survey, part ii, p. 569.

RÉSUMÉ

CAMBRIAN

The greatest development of the Cambrian rocks exposed in this region is in the Bighorn mountains, where they attain a thickness of 1,000 feet, comprising sandstones, shales, limestones, and intraformational limestone conglomerates. There is a relatively regular succession of beds throughout, and fossils of middle Cambrian age occur at several horizons. Probably the beds represent the Gallatin limestone and Flathead formation of south-central Montana, but as they more closely resemble the Cambrian succession in the northern Black hills, the name Deadwood formation is applicable to them. In the vicinity of Deadwood about 500 feet of Cambrian beds are exposed, comprising buff sandstones and shales in part glauconitic and the characteristic limestone conglomerates, all with middle Cambrian fossils. Formerly it was believed that the upper Cambrian was also represented. The thinning of the Deadwood formation in the southern Black hills appears to be due to overlap of the upper sandstone and absence of the lower beds, and farther south in the Hartville uplift and for many miles along the Laramie range and Rocky Mountain front the formation does not appear.

The brown sandstones underlying the Carboniferous limestones for a few miles at the north end of the Laramie range are presumably of Cambrian age, and probably mark the southern extension of the deposits so prominent in the Bighorn uplift. The small outcrops of sandstone about Manitou and north of Canyon City are of upper Cambrian age, and indicate local basins, or possibly local overlaps from an irregular margin of deposits which may be widespread under the plains eastward. The absence of beds of middle and lower Cambrian age in Colorado indicates that there was an extensive land area in the central Rocky mountains during these times, a condition pointed out to this Society by S. F. Emmons in 1890.*

ORDOVICIAN

In the Bighorn mountains, northern Black hills, and at a few detached localities along the Rocky Mountain front range, the Ordovician rocks appear overlying the Cambrian sandstone. In the Bighorn mountains they extend continuously around the uplift, and are termed the Bighorn limestone. The lower massive members, which are several hundred feet thick, carry a fauna of Trenton age, and the thin, overlying, softer beds carry a Richmond fauna of upper Ordovician age. The upper limits are somewhat indefinite, but doubtless there is a great planation unconformity and hiatus separating the Lower Carboniferous limestone. In the Black hills the Ordovician, which has been designated the Whitewood limestone, appears in the northern portion of the uplift and to a limited extent in the Bear Lodge range. It carries an upper Trenton fauna, and from this fact and the close lithologic similarity, it is believed to be equivalent to the lower massive member of the Bighorn limestone. The few feet of green shales which lie above the Whitewood limestone are of undetermined age. No evidence of Ordovician rocks were detected in the Casper or Laramie ranges, the Hartville uplift, or in the Rocky Mountain front ranges north of Denver. It is possible that they were deposited and removed by pre-Pennsylvanian erosion. The Ordovician rocks which appear in the central portion of the Front range in Colorado—the Manitou limestone, Harding sandstone, and Fremont limestone—contain a Trenton fauna, the Harding sandstone representing the lower Trenton and the Fremont limestone the upper Trenton.

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* Bull. Geol. Soc. Am., vol. 1, pp. 245-286.

SILURIAN-DEVONIAN

No deposits representing these two great periods of geologic time have been discovered in the area to which this report relates. They are surely absent in the Front range exposures in Colorado, but may possibly be represented in the green shale of the northern Black hills and in the zone of apparently non-fossiliferous limestones lying between the Bighorn and Littlehorn limestones of the Bighorn uplift. I think, however, it is much more likely that they are entirely absent along the east side of the Rocky Mountain uplift, although they may underlie a portion of the Great plains eastward.

LOWER CARBONIFEROUS

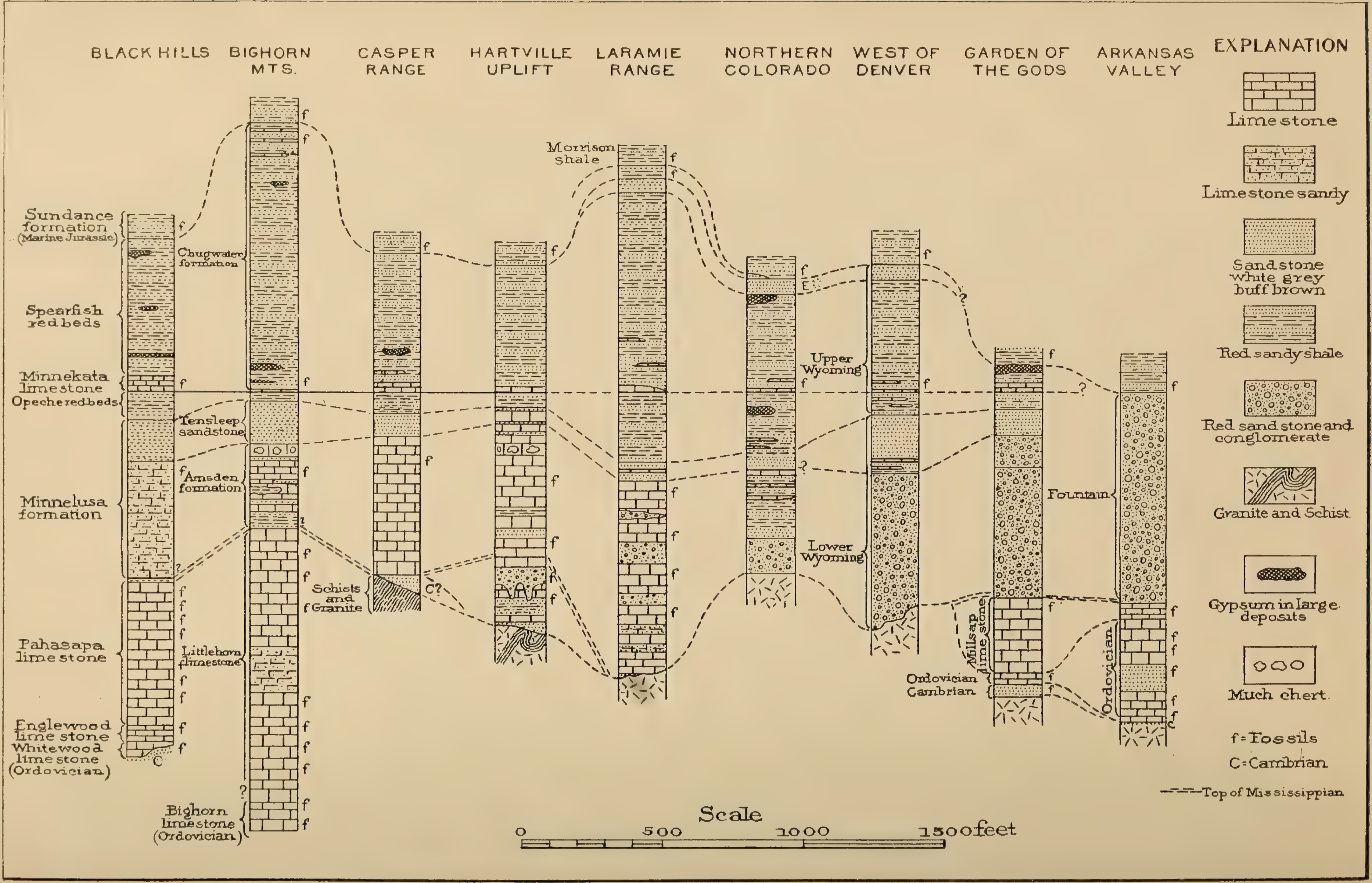
The Lower Carboniferous rocks are exposed principally in the Black hills and Bighorn uplifts, and a few small areas occur along the foot of the Front range, in Colorado. It is probable that these rocks extend widely under the Great plains, but no borings have gone deep enough to reach them, except in eastern Kansas and southeastern Nebraska.

In the Black hills the Mississippian is represented by two limestone formations, the Englewood and the Pahasapa, both containing an abundance of characteristic fossils, those of the Englewood being equivalent to the lowest Mississippian (Chouteau or Kinderhook) and the Pahasapa equivalent to the Madison limestone of the northwest. Some Leperditia in the concretions in red shale at the base of the Minnelusa are of a type characteristic of the Mississippian, especially at about the horizon of the Saint Louis limestone. It is possible that considerable of the lower part of the Minnelusa is also of Mississippian age, for it appears to be equivalent to the Hartville limestone. The Littlehorn limestone of the Bighorn uplift consists mainly of a representative of the Madison and Pahasapa limestones, and doubtless the Englewood is also included, but the upper limits of rocks of Mississippian age in both uplifts has not yet been ascertained.

Along the Laramie range the apparent absence of Lower Carboniferous is an interesting feature, indicating either non-deposition or removal by the very profound later Carboniferous erosion. A short distance eastward, in the Hartville uplift, there are comprised in the Mississippian the Guernsey formation, 150 feet or more in thickness, and the lower members of the Hartville formation, the two formations being separated by strongly marked erosional unconformity. The basal sediments of the Hartville formation are red sands, and there is strong suggestion that these are of the same age as the red shale at the base of the Minnelusa formation of the Black hills and base of the Amsden formation in the Bighorns. The representative of the Lower Carboniferous in Colorado appears in the small areas at Perry park, about Manitou, about Canyon City, and southwest of Pueblo, and is known as the Millsap limestone. This limestone lies unconformably on the Cambrian, Ordovician, and pre-Cambrian, and is unconformably overlain by the Fountain or lower Wyoming formation, which overlaps directly on the granites in most portions of the area. Its fauna is regarded as moderately early Mississippian.

UPPER CARBONIFEROUS AND RED BEDS

The classification of the formations representing later Carboniferous to Triassac time in this region is one of its most interesting problems. Upper Carboniferous and Permian fossils occur at several localities, but some of the sediments have yielded either no organic remains or fossils that do not afford satisfactory evidence as to age. The stratigraphy presents much diversity in different portions of the region, but by extended field work it has been found possible to correlate most of the rocks in the various uplifts. More or less of the Red beds, especially their upper members, have generally been classed in the Triassic, but there is no definite proof whether a representative of this period is present or not. The fossils which I discovered in 1901 in the upper limestones of the Red beds on the east slope of the Big Horns are thought to be Permian, but possibly they may be Triassic. The fossils of the southern Kansas-Oklahoma upper Red beds are regarded as Permian,


BLACK HILLS
BIGHORN MTS.
CASPER RANGE
HARTVILLE UPLIFT
LARAMIE RANGE
NORTHERN COLORADO
WEST OF DENVER
GARDEN OF THE GODS
ARKANSAS VALLEY
EXPLANATION
Limestone
Limestone sandy
Sandstone white grey buff brown
Red sandy shale
Red sand stone and conglomerate
Granite and Schist
Gypsum in large deposits
Much chert.
f=Fossils
C=Cambrian
Top of Mississippian
Sundance formation (Marine Jurassic)
Spearfish red beds
Minnekata limestone
Opeche red beds
Minnelusa formation
Pahasapa limestone
Englewood limestone
Whitewood limestone (Ordovician)
Chugwater formation
Tensleep sandstone
Amsden formation
Littlehorn limestone
Bighorn limestone (Ordovician)
Schists and Granite
C?
Morrison shale
Upper Wyoming
Lower Wyoming
Millsap limestone
Ordovician
Cambrian
Fountain
Ordovician
Scale
0
500
1000
1500 feet

COLUMNAR SECTIONS OF CARBONIFEROUS AND RED BEDS but the precise relations of these deposits to the Red beds of Colorado are not determined. In 1901 I found a fragment of a shoulder bone at the Red rocks in Purgatoire canyon in southern Colorado which Professor F. A. Lucas regarded as a portion of a Bolodont, an opinion which was sustained by Dr E. Fraas, and this genus is considered typical of the Triassic. The lower Red beds of the Rocky Mountain front range, which have yielded no fossils, undoubtedly merge into Upper Carboniferous limestones both to the north and south, and they can be correlated also with formations in the Bighorn mountains and Black hills. The suggestion that the lower Wyoming in Colorado is of Upper Carboniferous age was first made by S. F. Emmons in the monograph on the Denver basin.* According to G. I. Adams, the Red beds of south-central Kansas and southward merge into the limestone and shales of the Permo-Carboniferous series, and the evidence of this relation appears to be entirely satisfactory. It is certain that the Red beds represent a considerable interval of time, and the discovery of fossils at one horizon does not settle the age of the whole series.

Throughout the Black hills, Bighorn mountains, and much of the region south, the Upper Carboniferous and Red Bed series presents a general succession, as follows, beginning at the top: A thick mass of gypsiferous, red, sandy shales; thin mass of thin bedded limestone; thin mass of red, sandy shales; thick, hard, light-colored sandstone, and at base, limestones and sandstones giving place to sandstones and conglomerates, the basal series lying unconformably on Mississippian limestones, on Cambrian or on old granites and schists. The columnar sections in plate 35 illustrate some of the principal features.

In the Bighorn and Black Hills uplift the assignment of formations to the Upper Carboniferous or Pennsylvanian is somewhat provisional. A few fragmentary fossils were observed, but they were hardly determinative. The Minnelusa formation, which succeeds the Pahasapa (Lower Carboniferous), is a strongly marked series, supposed to be Pennsylvanian, in part at least, from a few fossils which I obtained in its upper beds near Hot Springs. These fossils were *Productus semireticulatus* and *Seminula subtilita* (?). In the slopes of the Bighorn mountains there is a series somewhat similar to the Minnelusa beds, which I have designated the Amsden formation and Tensleep sandstone. The former contain a basal red shale member suggesting the thin one which occurs at the base of the Minnelusa formation of the Black hills, and alternations of limestone and sandstone with much chert, which suggests the lower two-thirds of the Minnelusa formation, but with purer limestone deposits. These limestones have so far yielded only some fragmentary, indeterminate fossils. Next above is the Tensleep sandstone, very like the top sandstone of the Minnelusa in most portions of the Black hills, and similarly overlain by a great body of Red beds. In the Black hills these Red beds have three distinct subdivisions: the Opeche formation at the base, 60 to 120 feet thick; the Minnekahta or "Purple limestone," as it was termed by Newton, about 50 feet thick and of very characteristic aspect, and at the top several hundred feet of red, sandy shales, which have been designated the Spearfish formation. It is succeeded unconformably by the marine Jurassic. In the Minnekahta limestone fossils occur at many localities, comprising forms which are regarded as Permian in age. In the Bighorn uplift the Red Bed series is slightly thicker, but its character is nearly the same as in the Black hills. It has been designated the Chugwater formation. The Opeche series appears to be present at the base, but it is only 20 feet thick. It is succeeded by only a few feet of limestone, a probable representative of the Minnekahta, but unfortunately without fossils, so far as observed, and then a thousand feet or more of Red beds, believed to represent the Spearfish formation, and unconformably overlain by marine Jurassic. These Red beds contain gypsum deposits, as in the Black hills, but they differ in including several thin beds of limestone near their top. Fossils of several species are abundant in these limestones, but they do not indicate whether the age is Triassic or Permian. Passing south in Wyoming to the Laramie range, the lower members, the Upper Carboniferous series, change considerably, but the Red beds present the features which characterize them in the Black hills. The limestone on the Casper mountain and ranges southwest of Douglas are of Upper Carboniferous age and presumably represent the Amsden formation of the Bighorn uplift. Locally they lie on a sandstone which probably is Cambrian, but may be younger, and they are separated from the Chugwater Red beds by typical Tensleep sandstone. The tripartite subdivision of the Chugwater Red beds is established by the occurrence of typical Minnekahta limestone, notably in the big bend of North Platte river 6 miles south of Douglas and farther down the river in the basin northwest of Hartville. In the Hartville area the basal Red beds (Opeche) are underlain by the Hartville limestone, which is Pennsylvanian in its upper part and Mississippian at base. The top beds are sandy, suggesting Tensleep sandstone, and the limestones below, with cherty and sandstone layers, doubtless represent the Amsden formation of the Bighorns and the Minnelusa of the Black hills. No special search has been made yet for evidence of unconformity in the Hartville limestone at the top of the Pennsylvanian.

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* Loc. cit., p. 19.

In the Front range, northwest of Cheyenne, the stratigraphy is somewhat variable. The lower limestones lie directly on the granites and are apparently Upper Carboniferous, although no fossils were observed in the lower 100 feet. It has been suggested that the non-fossiliferous basal beds may represent the Lower Paleozoic series, but the overlap relations north and south do not sustain this, except that if the limestones represent all of the Hartville formation of the Hartville region the lower beds may possibly include rocks of later Mississippian age. The limestone series contains several red sandstone members, but at the top gives place rapidly to the thick body of Chugwater red shales. The Tensleep sandstone appears to be represented, containing thin layers of limestone in its middle and on Chugwater creek another one near its top. Then succeed typical soft red sandy shales, which, on Horse creek, include a 20-foot bed of limestone, apparently representing the Minnekahta horizon, a bed not found on Chugwater creek.

Near the Colorado-Wyoming state line the Upper Carboniferous limestones were found to merge into red sandstones, apparently by the expansion of included reddish sandy layers observed northwest of Cheyenne and a corresponding thinning of the limestone.* A mass of red sandstones and conglomerates, which lies at the base of the limestone for some distance, is seen also to thicken gradually to the southward. The product of this change is a great lower series of coarse Red beds, containing three thin limestone layers which persist for several miles. All through this region the supposed Tensleep sandstone horizon is well marked, and it was traced without difficulty southward to beyond the Garden of the Gods. It is the "Creamy sandstone" at the summit of the lower Wyoming of Eldridge, as described in the Denver monograph, and I feel certain that the conspicuous white sandstone ledge lying immediately in front of the gateway to the Garden of the Gods is undoubtedly the upper part of the southern extension of the same bed, so that it is an important horizon marker. Throughout its course in Colorado it marks the transition from the coarse deposits of the lower coarse Red beds (lower Wyoming) to the bright red gypsiferous shales of the Chugwater formation (upper Wyoming), although it is sharply demarked from both. It is possible that in the Denver region it comprises more of the Upper Carboniferous column than the topmost sandstone northwest of Laporte, for the two thin beds of limestone which it contains west of Denver suggest that it includes the extension of the thin limestones underlying the supposed Tensleep sandstone northwest of Laporte.

The thick mass of red sandstone sediments of the lower Wyoming is believed to represent Upper Carboniferous only, but, as suggested above, it includes also an expansion of shore deposits lying beneath the limestones near the Colorado-Wyoming state line, and these may possibly be rocks of somewhat greater age. In the southern extension of the lower Wyoming beds into Perry park they lie unconformably on fossiliferous limestones of Mississippian age, and a similar relation exists in the region west of Colorado Springs and at intervals southward. The presence of the unconformity between the Guernsey and Hartville formations in the Hartville region, and its possible extension in the Black hills and Bighorns, suggests that the same unconformity may extend south to and along the Laramie and Rocky Mountain fronts, especially at the top of the Millsap limestone. In this case the lower Wyoming Red beds would comprise some sediments of late Mississippian age.

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*A similar relation on the west side of the range has been described by Wilbur C. Knight in the Journal of Geology, vol. 10, pp. 412–422. The limestones were found to contain Upper Carboniferous fossils.

The name Fountain formation has been used to comprise all of the Red beds in the region northeast of Canyon City and southwest of Pueblo. and if, as I believe, the Chugwater (upper Wyoming) formation thins out a short distance south of the Garden of the Gods, the Fountain formation corresponds in the main to the lower Wyoming and it is the product of similar conditions at the same geologic epoch. I do not see the slightest reason for supposing that the two formations are not equivalent. The character of the beds northwest of Pueblo and in the Garden of the Gods region is precisely the same as in the district west and north of Denver, and, although I made special search, I could find no evidence of overlaps or unconformities of any kind within the great uniform mass of deposits of the Fountain or lower Wyoming formation.

The separateness of upper and lower Wyoming is very distinct from the Garden of the Gods northward to the state line, as recognized by the geologists of the Hayden survey, and clearly set forth in the Denver monograph, where the terms lower Wyoming and upper Wyoming were introduced. The upper Wyoming consists mainly of fine grained sediments extending from the "Creamy sandstone," which I believe to be the equivalent of the Tensleep, to the base of the Morrison formation. It consists mainly of bright red shales, always with a thin limestone layer or series toward its base, and, from Platte canyon northward, having a massive, pinkish sandstone at its top. The included limestone is believed to represent the Minnekahta horizon of the Black hills and other regions, indicating a short but widespread interval of limestone deposition at this period in the West. The few fossils found in this limestone unfortunately do not settle its age, but there appears to be but little doubt that its representative in the Black hills is Permian. The overlying red shales, with gypsum, in northern Colorado may be Permian or Triassic, for the fossils in the limestones which occur near the top of the extension of this series into the Bighorn uplift do not indicate whether the beds are Paleozoic or Mesozoic.

The Chugwater formation (upper Wyoming Red beds) is only 140 feet thick at the Garden of the Gods, and it appears to thin out and disappear a few miles southward, bringing the Fountain formation into contact with the Morrison—a relation due either to non-deposition of the Chugwater beds or to their removal by erosion in pre-Morrison times. As it is, the hiatus probably represents part of the later Carboniferous, the Permian, Triassic, and all of the Jurassic periods. South of the Arkansas river some of the Chugwater beds probably appear again, although at present their identity is not established. The Badito formation of Hills appears to be simply the Fountain formation of Cross and Gilbert. The Sangre de Cristo formation, to which Hills refers in the Walsenburg folio, appears to represent a great development of Fountain or lower Wyoming deposits. It is stated that remains of an Upper Carboniferous fauna and flora occur in this formation, which is added evidence as to the age of the lower Red Bed series (Fountain-lower Wyoming). These beds overlie or merge into the basal limestone series on the eastern slopes of the Sangre de Cristo (Culebra) range, in which Mr Willis T. Lee has discovered an extensive Upper Carboniferous (Pennsylvanian) fauna. The Red beds revealed in the canyons of southeastern Colorado can not be classified with certainty from the present evidence. On the Purgatoire river and Muddy creek the principal body of Red beds is separated from the Morrison formation by gypsum or gypsiferous shales strongly suggestive of the Chugwater formation (upper Wyoming), and it is immediately under this gypsum, in the Purgatoire canyon, that I found the shoulder bone of a supposed Bolodont. Mr Willis T. Lee has traced the Red beds farther southward into northeastern New Mexico, where the gypsiferous horizon gives place to a massive sandstone, termed the Exeter sandstone, constituting the summit of the Red beds, a member which may represent the distinctive top sandstone of the Chugwater formation in northern Colorado and southern Wyoming. It is prominent in the Two Butte uplift, constituting the summit of the Red beds, and is underlain by red shales which contain a thin bed of limestone noted by Mr Gilbert, strikingly like the Minnekahta horizon. I have not examined the Red beds in Kansas, and feel that a comparison of published statements with my observations in the regions north and west would not aid in the correlation.

SUNDANCE FORMATION

The Jurassic appears to exist only in the northwestern portion of the region to which this report relates, apparently owing to non-deposition in other portions of the region. In the Bighorn mountains and Black hills it is represented by from 300 to 400 feet of deposits, but these thin gradually to the southward in the Laramie range and disappear in the northern portion of Colorado. The thinning appears to be general at the outset and the upper beds probably disappear first, but this point has not been definitely determined, and it may be that the upper shales merge into sandy beds and these thin out gradually together with the underlying sandstones.

The formation is evidently of marine origin, as indicated by its numerous molluscan remains, and its age is regarded as late Jurassic. It has not been divided into subordinate members, but in its regular succession it presents a succession of beds and faunas which are constant over a wide area, especially the sandstone near the base and the green shales above containing numerous *Belemnites densus*. It is probable that the Sundance formation does not extend far east of the Black hills, nor to the southeastward of the locality at which it disappears in surface outcrops in northern Colorado, but there is no direct evidence on this question.

The Unkpapa sandstone which succeeds the Sundance formation along the eastern side of the Black hills is a relatively local feature of unknown age. It appears to represent a local shore deposit in late Jurassic times, prior to the deposition of the Morrison beds. The horizon may possibly be represented in other regions by the almost general occurrence of a yellowish sandy bed at the top of the Sundance formation. If not, it is probable that in the area in which it is absent there is a small unconformity or hiatus at this horizon. There is a very abrupt change from the Sundance to Morrison sediments, but no direct evidence of unconformity has ever been found.

MORRISON FORMATION

As the western portion of the Great Plains is explored, it has been found that the Morrison formation is very extensive in its distribution. It is seen nearly all the way around the Black Hills uplift, it extends along both sides of the Bighorn mountains, appears extensively in the Hartville uplift, and is traceable along the Laramie range, across Colorado, and far southward into New Mexico. Mr Willis T. Lee has found that it extends eastward in the canyons of southern Colorado and down the Cimarron river, where, near the Oklahoma-New Mexico line, apparently it merges into upper members of the Comanche series or both occupy the same horizon relative to the adjoining beds. I have recently found a similar relationship in the Two Butte uplift in the southern corner of Colorado.

The character of the formation is strikingly uniform throughout, consisting mainly of a mixture of clay and fine sand having a massive structure like joint clay and mainly of gray or pale greenish gray color, with portions which are purple, maroon, or chocolate. Beds of fine grained, light colored sandstones also occur, and in many districts, especially in the lower portion of the formation, there are thin beds of limestone in which I have lately discovered a fresh water algæ. At various horizons in both the clays and sandstones saurian remains occur, sometimes in vast quantities, and these have been collected extensively at Canyon City, in Morrison, and on the east side of the Black hills. I have recently observed similar bones along the eastern foothills of the Bighorn ranges and along both sides of the Bighorn basin as well.

The extent of the formation to the eastward, and especially to the northeastward, is not known. Probably it would be found in deep borings for some distance northeast of the Black hills, but it is absent in the eastern part of South Dakota, as well as in Nebraska and Kansas.

LAKOTA-DAKOTA SERIES

In 1893 Professor Lester Ward discovered that the so-called Dakota sandstone of the Black hills contained not only a Dakota flora, but, in its lower beds, an extensive flora of earlier Cretaceous age. As the Dakota sandstone in its type region is characterized by a distinct Upper Cretaceous flora, it became necessary to restrict the term "Dakota" in the Black hills to the upper sandstone carrying the upper Cretaceous plants. In investigating the stratigraphy of the uplift it was found that the upper sandstone is separated from the lower sandstone, which was designated the Lakota sandstone, by a persistent body of shales, which has been designated the Fuson formation. In tracing these formations northward it was ascertained that the principal plant-bearing horizon in the northern Black hills was in the Fuson formation, and this has yielded a large and beautiful flora of Lower Cretaceous plants, which Professor Ward has described. The tripartite composition of the Dakota group in the Black hills is very distinct throughout the uplift, and apparently it is a widespread feature in adjoining regions.

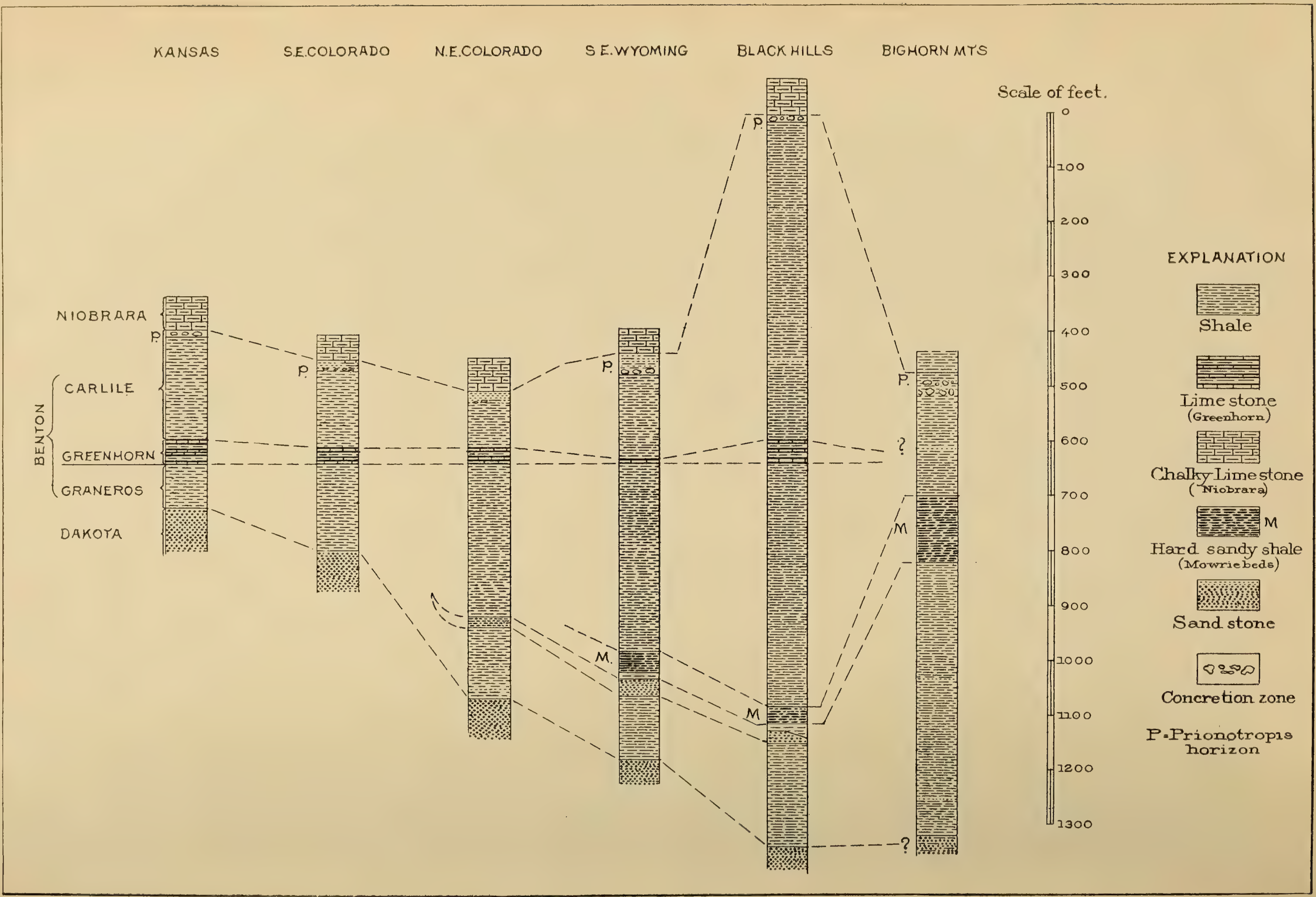
Along the eastern base of the Bighorn range there is a sandstone, believed to represent the Lakota, which is overlain by typical clays of the Fuson, but the Dakota sandstone does not appear unless it is represented by some sandy layers among the shales in the base of the next succeeding formation. This same relation is found on the west side of the Bighorn range, and it appears to extend far south in Wyoming. In tracing the beds southward through Wyoming the outcrops of this horizon are so discontinuous, owing to the overlaps of Tertiary deposits, that the stratigraphic conditions could not be definitely ascertained. Southeast of Casper some suggestion of the regular succession of Lakota, Fuson, and Dakota is found, but from the Laramie river southward there appears to be only one sandstone, which, so far as its character goes, might belong to either one sandstone member or the other. In Colorado there are usually two sandstones separated by a bed of fireclay, which strongly suggests the Lakota-Fuson-Dakota succession, but it has been supposed that all the rocks are of Dakota age. The intercalated fireclay series extends far southward through Colorado and eastward in the exposures of the Purgatoire and other canyons.

Throughout Colorado and eastern Wyoming, as in the region northward, the sandstones are underlain by the Morrison formation, excepting at a very few localities, and although there is general unconformity, it is difficult to believe that this represents Lakota and Fuson time. The Morrison materials are soft, and if they were exposed to erosion for such a long period, they undoubtedly would have suffered deep and widespread degradation. It is unlikely also that the Lakota and Fuson could have been deposited in regular order, and then been so completely and evenly removed as to leave the present stratigraphic relations of the Morrison to its overlying sandstones. A discovery very significant in this connection has been made by J. B. Hatcher, that dinosaur remains of Morrison type occur in the lower members of the overlying sandstone beds north of Canyon City, which indicate that there could have been no great time break at this horizon.

For these reasons it is probable that the Lakota-Fuson-Dakota series extends southward in Wyoming and Colorado, and possibly careful search in the medial fireclays and lower sandstones will yield lower Cretaceous plants.

BENTON GROUP

The rocks of this group are the most widespread and constant in characteristics of all the sedimentary deposits of the Central Plains region. The general feature of a thick succession of shales overlying the Dakota sandstone is the salient one, but widespread subdivisions or horizons of variation have also been recognized. Its thickness is variable, ranging from about 400 feet in the southeast to 1,600 feet in the Black hills. In nearly all the half million square miles under consideration the group comprises three members—a basal dark shale series known as the Graneros shales, a medial limestone known as the Greenhorn limestone, and an upper shale series with sandy layers, known as the Carlile formation. Toward its base the Graneros shale includes a horizon marked by thin but extensive layers of sandstone. The Greenhorn limestone always presents alternations of slabby limestone and shales, and the Carlile formation generally has a sandstone bed at or near its



COLUMNAR SECTIONS OF BENTON GROUP

top, while concretions usually occur not far below this sandy horizon. The Greenhorn limestone is characterized by great colonies of *Inoceramus labiatus*, a species which rarely is found at all in other horizons, while in the upper portion of the Carlile occurs *Prionotropis woolgari*, which appears to be restricted to that horizon and to characterize it throughout the region and even in the Bighorn basin. Throughout eastern Wyoming and the Black Hills region there is in the middle part of the Graneros shales, not far above the local sandstone horizon, a series of hard gray shales and thin bedded sandstones filled with fish scales, which weather to light gray color and from their hardness give rise to a ridge or cliff. These have been termed the Mowry beds, and they are conspicuous along both sides of the Bighorn, all around the Black hills, and along the Laramie front to the Colorado line.

In plate 36 sections are given showing the principal stratigraphic features of the Benton group in different districts. The variations in thickness are very striking, especially between 400 feet in Kansas and 1,300 feet, which is the average thickness in the Black Hills region. The salient features in the Kansas section are the Greenhorn limestones, comprising several limy layers having in all a thickness of 60 feet, of which 40 feet near the middle are characterized by large numbers of the typical *Inoceramus labiatus*. The Kansas geologists have included about 50 feet of the basal shales of the formation in the Dakota, but the reasons for this inclusion are not convincing, and I should be inclined to regard the saliferous and gypsiferous shales as comprising the lower portion of the Graneros. The three main subdivisions are readily distinguishable throughout eastern Colorado, where the formation gradually increases in thickness, mainly by the expansion of lower beds. In this region also there first appears, near the base of the Graneros formation, a bed of sandstone which varies greatly in thickness, but often gives rise to a conspicuous subordinate hogback ridge lying east of the main "Dakota" hogback, or on its slope. In southeastern Wyoming a further increase of thickness is exhibited. Here the Greenhorn limestone finally becomes thin and discontinuous approaching the end of the Laramie range and it is not recognizable at all in the sections along the Bighorn uplift. It is, however, a conspicuous feature in the slopes adjoining the Black hills, extending entirely around that uplift and often attaining a thickness of 50 feet. The sandstone in the lower portion of the Graneros appears to extend almost continuously through southeastern Wyoming and it appears at intervals around the Black hills, notably at Newcastle, Hermosa, and at the northern end of the uplift, but it does not appear in the Bighorns unless possibly at one locality.

The Mowry beds, consisting of hard shales and thin sandstones with fish scales, weathering light gray, appear first in southeastern Wyoming and are a conspicuous feature northward at a horizon a short distance above that of the sandstone in the lower part of the Graneros beds. They attain their greatest prominence along the Bighorns and around the Black hills.

The Carlile formation does not vary greatly in thickness through Colorado and southern Wyoming, but it expands greatly in the Black hills to over 500 feet in most parts of the uplift. It is not, however, characterized in the Bighorn uplift, but doubtless is represented in the gray shales lying not far above the Mowry beds. Owing to the absence of the Greenhorn limestone in this uplift, the lower limit of the formation is not indicated, but its upper portion is characterized by a zone of sandy concretions containing *Prionotropis woolgari*, a horizon which is characteristic as marking the upper limit of the Benton group throughout its course. These concretions are especially numerous around the Black hills and in Kansas. The top of the Carlile is also often marked by sandy sediments, and a top sandstone is a prominent feature in eastern South Dakota, through Colorado, and in southeastern Wyoming. In a portion of the Arkansas valley the upper sandstone is replaced by a thin bed of purplish limestone carrying Prionocyclas.

In eastern South Dakota the Benton group comprises a thin mass of Graneros black shales below, the Greenhorn limestone associated with some chalkstone, and a considerable thickness of Carlile shales. At or near the top of the Carlile formation there are concretions and a nearly general bed of sandstone from 15 to 50 feet thick, and in places considerably thicker.

NIOBRARA FORMATION

This deposit occupies a wide area in the central Great Plains region, succeeding the Carlile formation without unconformity, and, excepting in the vicinity of the Bighorn mountains, it consists largely of carbonate of lime. Its thickness varies considerably from apparently less than 100 feet in some portions of eastern South Dakota to 700 feet in central southeastern Colorado.

At the type locality on the Missouri river, at the mouth of the Niobrara, the formation is represented by chalk rock having a thickness of about 200 feet. In southern Nebraska and Kansas, where it appears extensively, the amount is considerably greater, 350 feet being the estimate by the Kansas geologists. The formation usually presents purer and harder carbonate of lime deposits near its base, constituting the Fort Hays limestone in Kansas and the Timpas formation in Colorado. The characteristic fossil of this horizon is the *Inoceramus deformis*, which is a conpicuous feature in Colorado and for some distance northward into Wyoming.

Along the foot of the Rocky Mountain and Laramie front ranges the formation usually presents three limestone layers—a lower massive bed and two upper layers, separated by limy shales, the uppermost overlain by impure limestones, which weather to a bright yellow color and always contain numerous flat masses of limestone consisting of colonies of *Ostrea congesta.* The formation thins to the northward in Colorado and Wyoming, becoming about 400 feet thick northwest of Cheyenne. On the slopes of the Black hills the average amount is about 200 feet, but the amount is about 100 feet at the north end of the uplift. The bright yellow color of the weathered beds is a conspicuous feature. The formation is not characterized along the eastern slopes of the Bighorn mountains, although doubtless it is there represented by some gray shales, not distinguishable from those of the adjoining formation, which carry Carlile fossils below and Pierre fossils above.

PIERRE

The great shale series of the Pierre formation occupies a vast area in the central Great plains, and probably originally it was of greater extent, for apparently it has been removed by erosion in the mountain uplifts and in eastern Nebraska and southern and eastern Kansas. No special investigation has been made of the Pierre stratigraphy, and, although the beds appear to be very uniform in composition, probably a careful study of the distribution of its numerous fossils would show widespread stages. One of these is the upper horizon of concretions with *Lucina occidentalis*, giving rise to "tepee buttes," which appears to extend from the Arkansas valley through Colorado to and all around the Black hills. In places along the western margin of the area great variations in thickness are presented, the shales becoming thicker and local sandstone beds being included. West of Denver the formation appears to have a thickness of over 7,700 feet, and it is considerably over 3,000 feet thick at Florence and near Boulder.

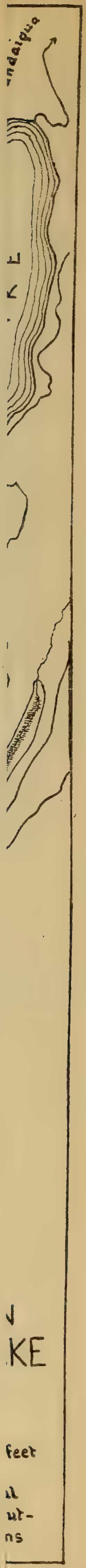
FOX HILLS

The Fox Hills formation appears to be present everywhere between the Pierre shale and the Laramie formation, merging into both formations and constituting beds of passage between them. In some districts the Fox Hills beds begin abruptly, there being a sudden change from the dark shales of the Pierre to sandstones or sandy shales of the Fox Hills containing some distinctive species. It is probable that this change does not take place at the same horizon throughout, and the Fox Hills fauna appears in connection with the sandy sediments.

Usually the Fox Hills deposits are less than 300 feet thick, but in the Denver region, where they comprise a thick mass of sandy clays in their lower portion, they attain a thickness of a thousand feet. The top member in this region is a persistent characteristic sandstone 50 feet thick, which appears to be the same as the Trinidad sandstone in the Spanish Peaks district in southern Colorado. The top of the Fox Hills formation is not always clearly defined, but in most cases the Laramie beds, being the product of shallow and fresh waters, are distinctive in character.

LARAMIE

This great series has received no special study in connection with the present investigation, and it has been separated from the adjoining formations only in a few localities. The work of Cross in the Denver basin and of Hills in the Spanish Peaks region has shown that it is of less thickness than originally supposed, and the great mass of overlying coarse sediments are of early Tertiary age. The thickness of the formation, as thus delimited, averages about a thousand feet in the Denver region and nearly twice as much in southern Colorado.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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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FINGER LAKE REGION OF WESTERN NEW YORK

BY CHARLES REDWAY DRYER

(*Read before the Society January 1, 1904*)

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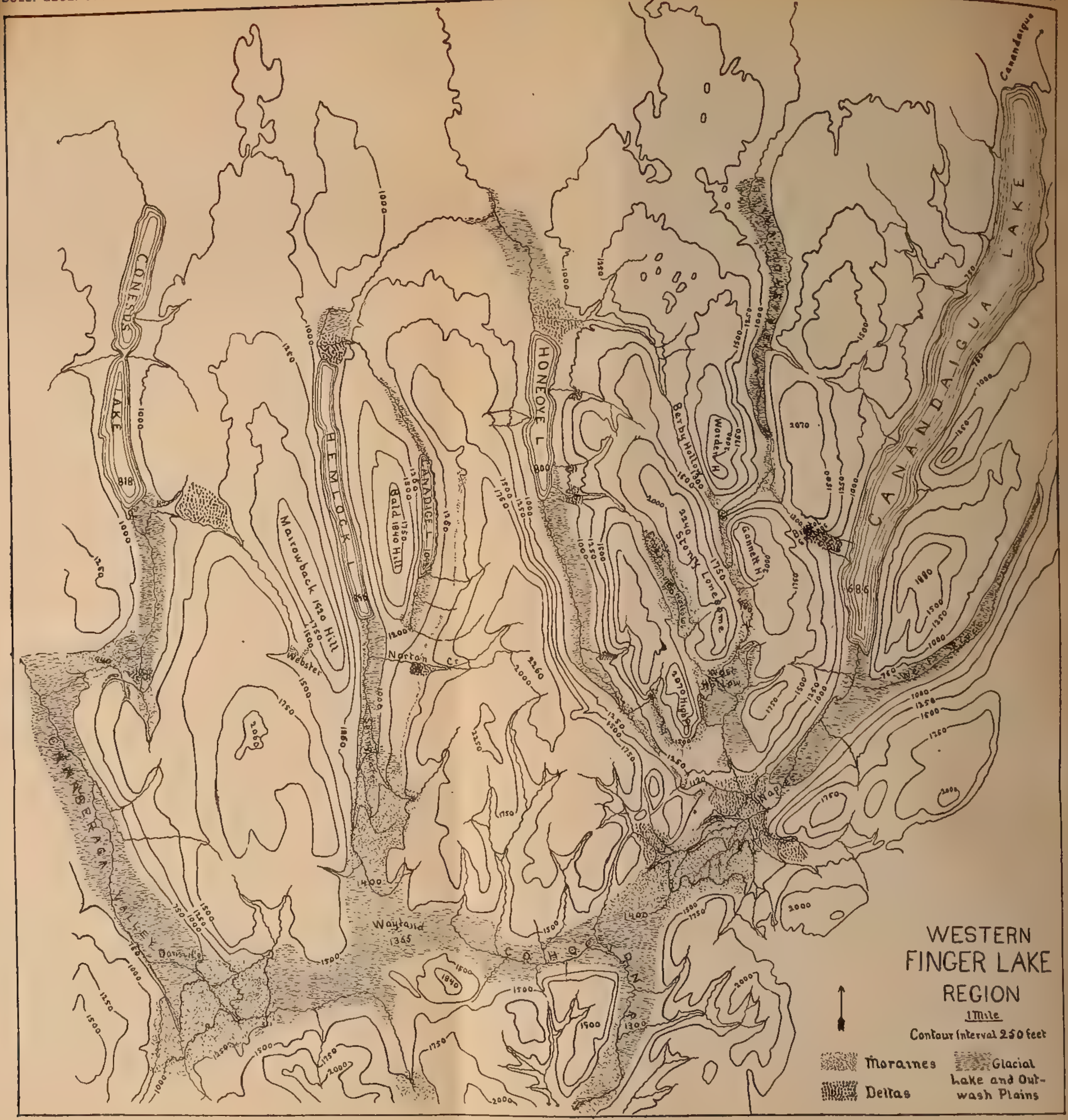
LOCATION AND GENERAL DESCRIPTION

The region discussed is that part of the Allegheny plateau in western New York which lies between the Canandaigua valley on the east and the valley of the Genesee river and its tributary, Canaseraga creek, on the west. It covers the northward slope of the plateau, here about 20 miles long. At its northern limit the distance from the foot of Canandaigua lake to the Genesee river is 25 miles. It is bounded on the south by the Cohocton-Wayland valley, which connects the head of Canaseraga with the head of Canandaigua, only 10 miles apart. It includes the four western finger lakes—Honeoye, Canadice, Hemlock, and Conesus—all of which are tributary to the Genesee. The plateau rises from an elevation of about 800 feet on the north to a crest above 2,000 feet in the southern part of the region. Its northern third is underlain by the Marcellus,


WESTERN
FINGER LAKE
REGION
1 Mile
Contour Interval 250 feet
Moraines
Glacial Lake and Outwash Plains
Deltas
CONESUS LAKE
818
HEMLOCK L
CANADICE L
HONEOYE L
800
CANANDAIGUA LAKE
686
Canandaigua
Marrowback Hill 1920
Bald Hill 1840
Webster
Norton Cr.
Berby Hollow
Worden H
Stony Lonesome
Gannett H
2070 High
2070
1880
West Hollow
Naples
Wayland
1365
Dansville
COHOCTON
CANASERAGA VALLEY
1840
2060
1000
1250
1500
1750
2000
2250
1400
1300

WESTERN FINGER LAKE REGION

Hamilton, and Genesee shales, its middle by the sandy shales of the Portage group (Naples beds), and its southern by the sandstones and shales of the Chemung. All except the Chemung sandstones are thin bedded and friable rocks. The region is nearly all included in the Canandaigua, Naples, Honeoye, and Wayland quadrangles of the topographic atlas of the United States.

This region is not unknown to geologists. It has been studied by James Hall, Chamberlin, and Fairchild. Each has given attention to special features, and has recognized and solved some of the many problems in which it richly abounds, but no one has attempted a general survey and correlation of data or made an exhaustive study of details in any one group. Its complete history can not yet be written, but this paper is offered as a contribution to that end.

Valleys and Ridges

The most conspicuous topographic features are the deep, narrow south-north valleys and the broader ridges between. The principal valleys are nearly straight, more than 1,000 feet deep, and from one-half mile to two miles wide at the bottom. They attain their greatest depth within a few miles of the head, and through three-fourths of their length their floors are flat and have little or no slope. All are dammed at the lower end by glacial drift, through which the outlet streams have cut gorges. They present the same general characters as the larger Finger Lake valleys to the east, but possess also some peculiarities, which make them worthy of special study.

The ridges present a general similarity of form, with a great variety of detail. Their crests in cross profile are flat or gently rounded, but in longitudinal profile are cut by shallow transverse passes into a series of elongated domes, which often present a drumlinoid curve.

Marrowback hill, on the west side of Hemlock valley, is 9 miles long by about 3 miles wide. Its crest rises gently to a summit near the south end, 1,920 feet above tide. It is cut off on the southwest by a diagonal pass at a level near 1,300 feet.

Bald hill, between Hemlock and Canadice valleys, is a symmetrical and completely isolated ridge 6 miles long and 2 miles wide. Its form is that of a perfect drumlin, with a summit at 1,840 feet near the south end.

About the heads of Honeoye, Bristol, and Canandaigua valleys the plateau is more thoroughly dissected, and presents many isolated domes and peaks, which rise 300–600 feet above the surrounding valleys. The surface of the plateau mass, 6 to 12 miles wide, between Honeoye and Canandaigua valleys, is complicated by high-level north-south valleys, connected by still higher passes. Between them massive domes rise to

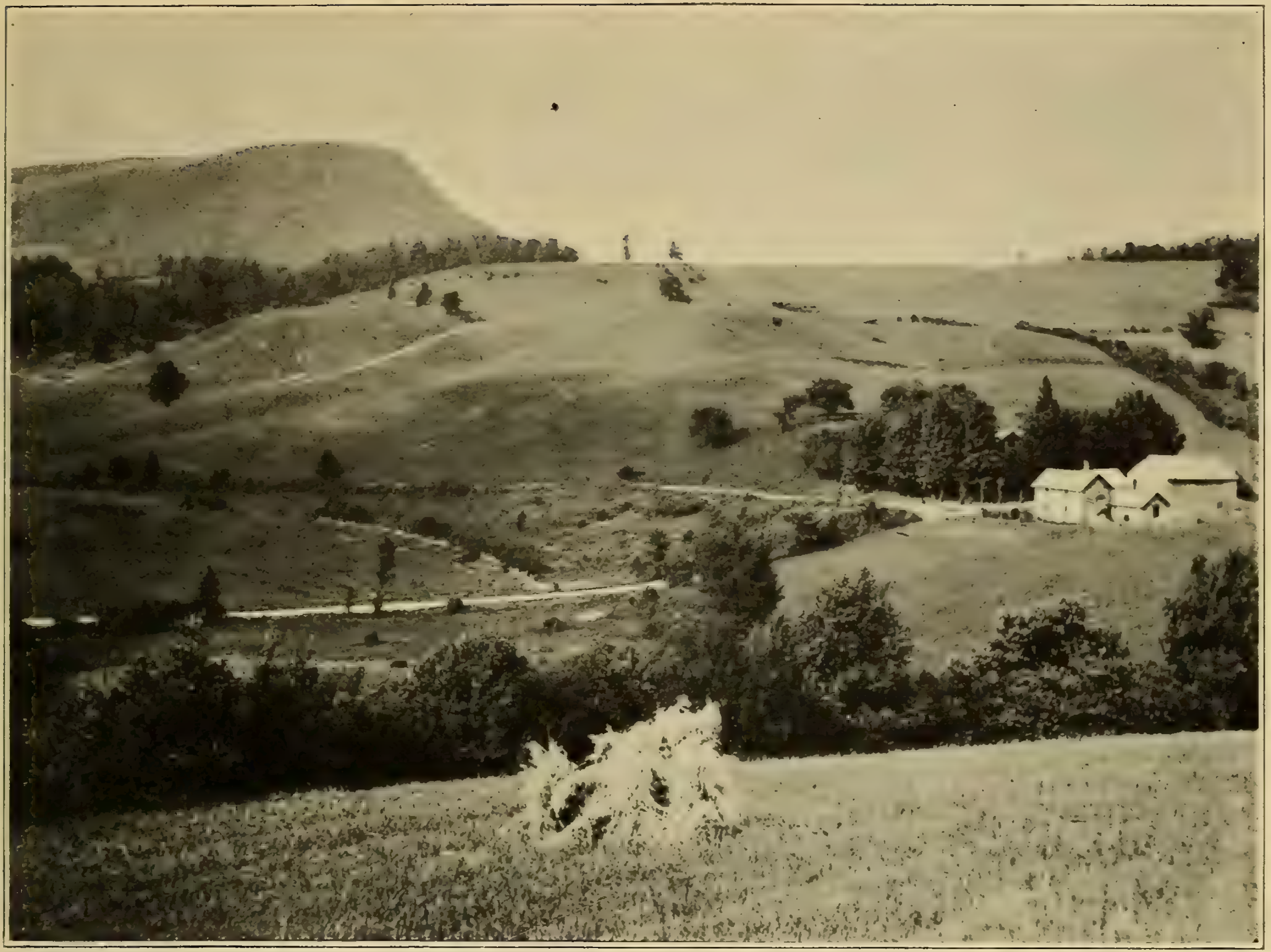


Figure 1.—Head of Honeoye Valley

View from west moraine dam looking north. Dam on right; slopes of High Point moraine in middle distance; High Point on left; level of West Hollow outwash plain on right in distance

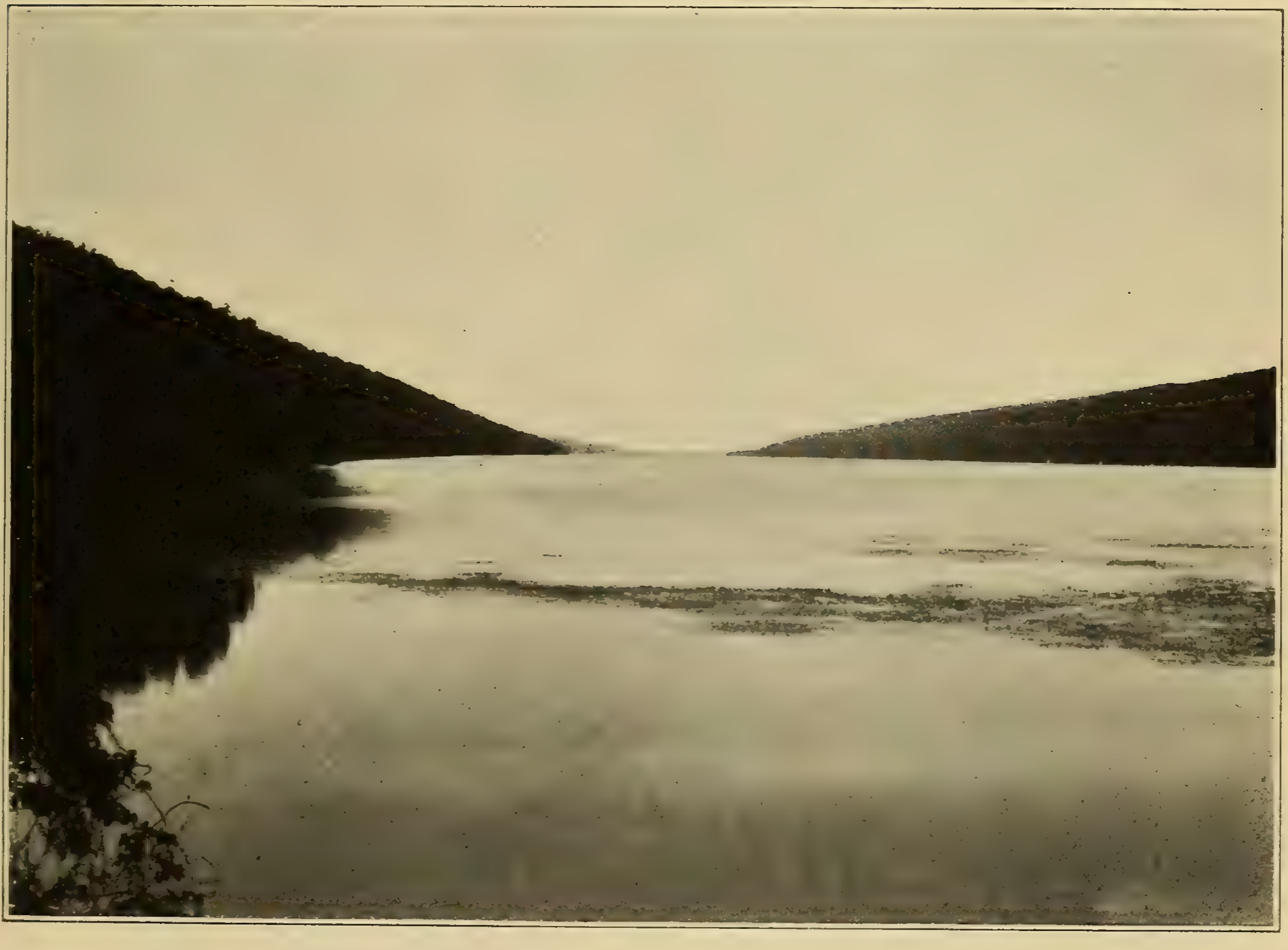


Figure 2.—Hemlock Lake looking north from the Head

HEAD OF HONEOYE VALLEY AND HEMLOCK LAKE

the highest levels of the region, a dozen of which are above 2,000 feet and two above 2,250 feet. The south ends of the ridges are often very abrupt, as in the case of High Point and Stony Lonesome. In many cases the slopes have been oversteepened. Of this the west side of Hemlock lake, both sides of the upper Honeoye valley, the east side of High Point, and the west sides of Worden and Gannett hills are notable instances. The east side of High Point has an angle of 40 degrees (figure 1, plate 38). The steeper slopes are scored by hundreds of sharp postglacial ravines, some of which are 200–300 feet deep, but they are so narrow as to be inconspicuous from a distance, and the general appearance of the slopes is smooth. They are occasionally broken by flat or gently sloping terraces of considerable width, due to the presence of more resistant strata at that level.

CANANDAIGUA VALLEY

It is not my purpose to enter upon a detailed description of the Canandaigua valley, but only to note its relation to the other valleys described. From Canandaigua it extends south-southwest 24 miles. Its lower 16 miles is occupied by the lake with a maximum width of one and one-half miles, narrowing to three-fourths of a mile at its head. The lake surface is 686 feet above tide, while the plateau summits on either side are 1,000–1,400 feet higher. At Naples, 4 miles above the lake head, the valley, joined by converging tributaries, widens into an amphitheater filled with deltas and moraines on a magnificent scale. These have been described by Chamberlin* and Fairchild.† The valley continues southwestward 4 miles, rising up the slope of the moraine 600 feet, and opens into the Cohocton-Wayland valley at the 1,400-foot level, precisely as the Canaseraga valley opens into it 10 miles to the westward.

CANASERAGA VALLEY

Canaseraga creek is one of the eastern tributaries of the Genesee, which it joins near mount Morris. Its valley, straight, flat floored, swampy, and more than a mile wide, extends east of south 15 miles to Dansville, rising from 577 to 700 feet above tide. Above Dansville it is blocked by a moraine, in every respect the counterpart of the moraine at the head of the Canandaigua valley. With a step up of 600 feet in 2 miles, it is continuous to the eastward with the Cohocton-Wayland valley.

COHOCTON-WAYLAND VALLEY

The east-west valley, 10 miles long and more than a mile wide, which connects the Canandaigua valley above Naples with the Canaseraga valley above Dansville, is one of the unique and striking features of the region. Four miles from the west end the Hemlock valley opens into it from the north. It thus cuts across the heads of three of the principal south-north valleys, and is similar to them except that its floor lies 500–600 feet higher. Its walls rise abruptly 500–650 feet, and it has the appearance of a half-filled valley, an inference which is sustained by the gravel pavement which lies a few feet below its surface. No deep borings have been made in it. At Wayland, opposite the junction of the Hemlock valley, a nearly isolated hill of Chemung sandstone 475 feet high projects into it from the south, and it is otherwise less regular than the south-north valleys. An extensive swampy tract 4 miles long, underlain by a deposit of marl, forms a divide from which a small stream flows westward to the Canaseraga, and another flows eastward to join the Cohocton-Chemung-Susquehanna drainage. At the junction of the Canandaigua valley the Cohocton valley turns abruptly to the south and contracts to one-half its former width.

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*Third Report, U. S. Geol. Survey, p. 354.

†Bull. Geol. Soc. Am., vol. 6, p. 362.

Conesus Valley

The north-south portion of Conesus valley is 12 miles long and three-fourths of a mile wide. Its upper end turns abruptly and, extending westward 3 miles without contraction, joins the Canaseraga valley at right angles. Conesus lake occupies the northern half of the valley, having a length of 8 miles, a width of three-fourths of a mile, and an area of 5 square miles. Its surface is 818 feet above tide. It is divided midway by deltas whose points are only 900 feet apart. The northern half projects beyond the plateau, and the valley slopes are gentle, 200 feet high, and heavily drift-covered. This part of the lake has a smooth floor and a depth along the middle line between 35 and 45 feet. The southern half has bolder shores which rise 300–400 feet in a mile and a maximum depth varying in ten cross-sections from 52 to 62 feet. At the head of the valley the walls rise 500–600 feet, and the floor rises from lake level to a divide 120 feet above the lake. The divide seems to be a dam of smooth till, without any suggestion of morainic topography, and slopes westward 400 feet in two miles to the floor of the Canaseraga valley. No shale appears in the ravines for at least 200 feet down, or to a level below the bottom of the lake. Conesus outlet flows through a drift gorge 100 feet deep to the Genesee river near Avon.

Hemlock Valley

Hemlock valley extends in an almost straight north-south line 16 miles. Its southern end is blocked by a moraine similar to those of the

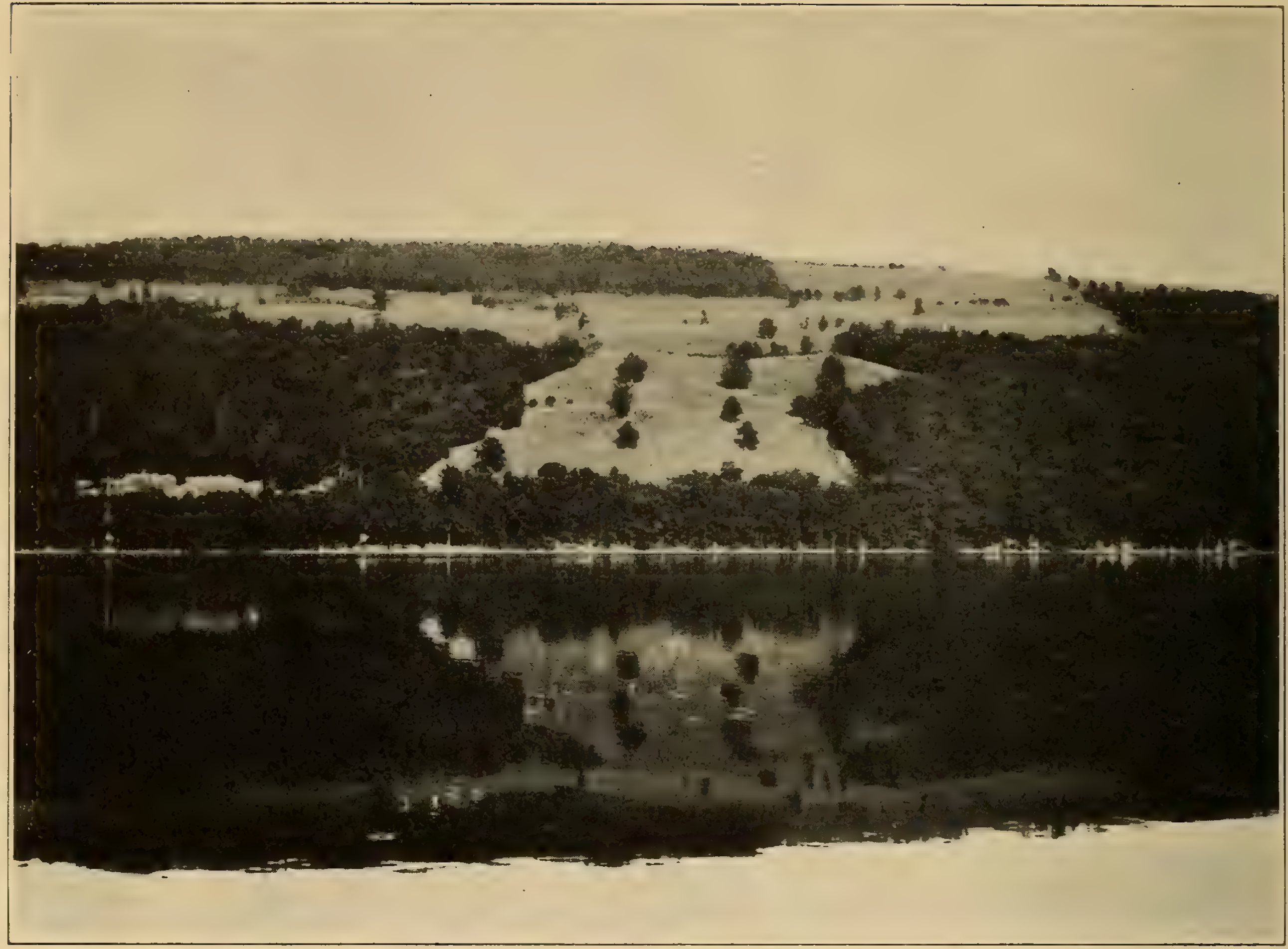

FIGURE 1.—EAST SIDE OF HEMLOCK LAKE, NEAR HEAD
Steep slope forested

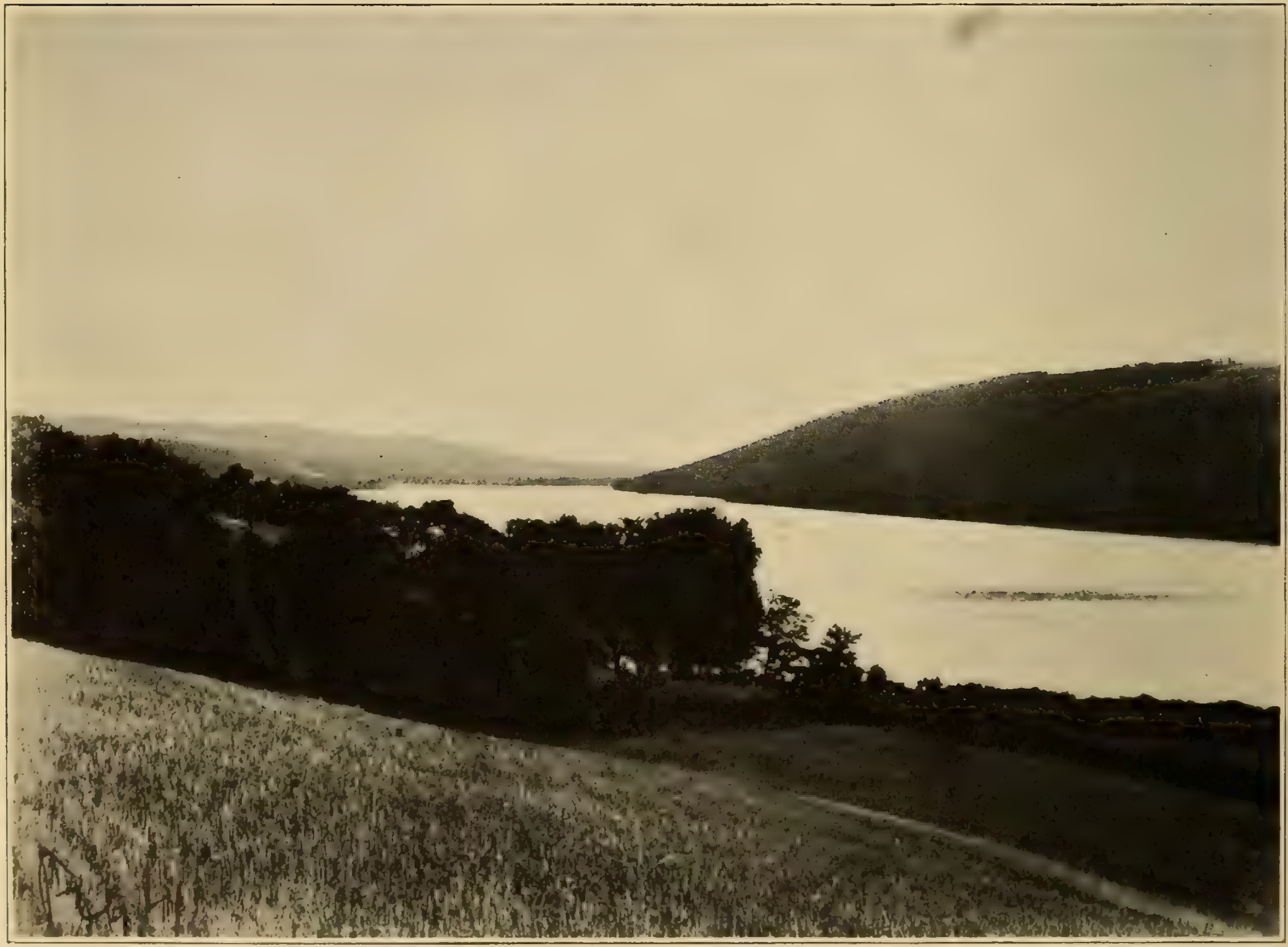

FIGURE 2.—CANADICE LAKE
View looking south from near the foot; bald hill on right

SLOPES OF HEMLOCK LAKE AND CANADICE LAKE

Canandaigua and Canaseraga valleys and opens broadly into the Cohocton-Wayland valley at right angles, with a step up of 500 feet. A valley which extends 4 or 5 miles south from Wayland may have once been the head of Hemlock. The boundary walls of Hemlock valley rise very steeply 500–900 feet, with slopes but slightly roughened by more than 200 post-Glacial "gulls" or ravines. Its northern half is occupied by a lake which presents within a space which can be embraced in one view the characters of a finger lake in an exaggerated degree (figure 2, plate 38). It is 35,000 feet long, its width varies from 1,975 to 2,650 feet, its area is 1,828 acres, and its surface is 896 feet above tide. It forms the public water supply of the city of Rochester, and by the courtesy of the superintendent of the Rochester water works I was enabled to make about 200 soundings and to determine with sufficient accuracy the bottom contours. The basin proved to be a simple boat-shaped depression with very steep side slopes and nearly level bottom rising gently toward each end. The maximum depth at a point south of the middle is 90 feet.

The lake fills the valley so completely as to leave no room for a coastal plain or shelf. Except at numerous small points or deltas, the shores rise from the water's edge at an angle of about 30 degrees, sometimes a little more or a little less, and near the head of the lake reach an altitude on either side of 1,000 feet above its surface within a distance of 1 mile. On the west side the slope of 30 degrees continues to a height which varies between 310 and 490 feet, where the angle changes abruptly to about 15 degrees. On the east side the slope is less steep, but the shoulder or abrupt change of slope appears between 210 and 350 feet. This level is conspicuous from the fact that the lower and steeper slopes are generally forested, their upper edge being the limit of cleared land, and there most of the smaller ravines begin (figure 1, plate 39).

Hemlock outlet flows through a drift gorge with a fall of 120 feet in 5 miles to the north end of the Honeoye valley.

CANADICE VALLEY

Canadice valley lies parallel with Hemlock on the east, being separated from it by the drumlin-shaped ridge of Bald hill. It is 8 miles long, three-eighths of a mile wide, and 850 feet deep. Its middle third is occupied by Canadice lake, 3 miles long, one-fourth to three-eighths of a mile wide, and having an area of 648 acres. The lake surface is 1,092 feet above tide. Its basin is the counterpart of that of Hemlock, with a maximum depth of 84 feet. The general slope on the west side is nearly as steep as that of Hemlock, but on the east side about one-half as steep. Neither slope presents any oversteepening in the lower portion (figure 2, plate 39). The valley is slightly curved, so that it opens into the east side of Hemlock valley at both ends. At the south end the floor of Canadice valley is 300 feet above the floor of Hemlock, and at the north end 160 feet. At both ends the floor is very thinly covered with drift. Canadice valley therefore bears to Hemlock valley the relation of a hanging valley at both ends.

Canadice outlet flows northward over a drift bed 2 miles with a fall of 40 feet; thence through a gorge cut in shale and over rapids, which fall 60 feet in one-eighth of a mile, to the Hemlock valley at the foot of the lake, where it has built a broad alluvial fan.

Honeoye Valley

The central position, length, and low level of the Honeoye valley indicate that it was made by an important pre-Glacial stream of the region. From the drift dam at its lower end it extends southward, with a gentle curve to the southeast in its upper part, 17 miles, to the point where it opens into the west side of Canandaigua valley, above Naples. In the lower two-thirds the flat floor varies in width from three-fourths to 1 mile, and is partly covered by the shallow and somewhat irregular Honeoye lake, nowhere more than 30 feet in depth. Its surface is 800 feet above tide. In the lower third the valley slopes rise 700 to 800 feet in a mile and a half, while farther south the walls increase in steepness and height to 1,200 feet within less than one mile. This is the steepest slope of equal height observed in the region. The upper third is narrow and choked with morainal deposits. The swampy col at its head is 1,150 feet above tide, while on either side the crest of the plateau reaches levels above 2,000 feet (figure 1, plate 38). Honeoye outlet flows northward through heavy drift deposits to the Rush-Victor glacial drainage channel, which it follows westward to the Genesee.

Bristol Valley

Bristol valley lies 6 miles east of Honeoye and parallel with its lower portion. It is 10 miles long, and its width varies from one-fourth to three-fourths of a mile. The floor rises from 760 feet above tide at the north end to 1,080 feet at the south. The walls are steep throughout and their height increases from 400 feet at the lower end to more than 1,000 feet at the upper. At South Bristol, Gannett hill, one of the highest summits in western New York, 2,256 feet above tide, stands directly athwart the valley which divides around it. The southeastern fork is a narrow moraine-choked pass, which leads over a col at 1,300 feet to Bristol Springs, where it opens into the west side of Canandaigua valley. A large delta lies on the slope below the notch. The southwestern fork is more open, and on the west side of Gannett hill leads southward over a col at 1,680 feet into West hollow, to be described later.

Bristol valley is drained by Mud creek or Ganargua river, which escapes northward through the drumlin belt to the Clyde-Oswego drainage. The depth and narrowness of Bristol valley, the numerous "gulls" or ravines which score its sides, many of which contain falls, the boldness and increasing height of its walls, and the abrupt promontory at its head, give it a wild and picturesque character which is unique among the valleys of the region.

HIGH-LEVEL VALLEYS

The plateau surface is broken by many high level valleys, each of which presents its own peculiar problem. Among them three are worthy of especial notice.

Berby hollow lies 2 miles west of the upper part of Bristol valley and parallel with it. It is 4 miles long and descends from 1,300 feet at the south end to 1,100 feet at the north, where it is drained through the gorge of Mill creek to the Honeoye. It differs from the larger valleys in being sharply V-shaped. Its slopes rise steeply 600 to 900 feet. At the south end it merges into and is continuous with the west fork of Bristol valley.

Frost hollow lies between the west fork of Bristol valley and Honeoye valley. It is 3 miles long and half a mile wide. It is occupied in part by a swamp at the 1,700 foot level, but more than half the area of its floor is covered by a kame-moraine, which at the south end rises up the slopes more than 100 feet. It once contained a small lake, but a kame ridge across its middle now forms a divide, from which a stream flows northward through Briggs gull to the Honeoye and another southward into West hollow.

West hollow is a continuation on the south of Frost hollow and the west fork of Bristol valley. It is 1 mile wide and nearly 3 miles long. Its surface is wholly occupied by a beautifully pitted outwash plain from the moraines on the north, and slopes gently southward from the 1,500 to the 1,400 foot level. The southern margin drops abruptly to the junction of the Honeoye and Canandaigua valleys (figure 1, plate 38). The glacial drainage from West hollow combine with that from the Honeoye glacial lake to form the great delta above Naples.

MORAINES

CLASSIFICATION

The principal moraines of the region were described by Chamberlin twenty years ago, and it will suffice to recall their location and to note the existence of others less conspicuous, but perhaps not less significant. They belong to two classes, (1) terminal or valley-head moraines and (2) lateral or valley-side moraines.

VALLEY-HEAD MORAINES

Three of the principal valleys terminate in massive moraines which fill them to the height of many hundred feet and widen upward as the valley widens. The summit of each is level with the outwash plain of the Cohocton-Wayland valley. At the head of Canaseraga valley above Dansville the moraine is 3 or 4 miles wide and rises 600 feet in 2 miles. At the head of Hemlock valley above Springwater the moraine is a mile and a half wide and rises 400 feet in 2 miles. At the head of Canandaigua valley above Naples the moraine is 2 miles wide and rises 600 feet in 3 miles. The topography is of a very pronounced knob-and-basin type. These three moraines are contemporaneous. An earlier series is represented for the Hemlock ice lobe by a moraine near Loon lake, 5 miles south of Wayland, and for the Canandaigua lobe by a moraine at Liberty, 4 miles down the Cohocton valley. Members of a later series occur above Scottsburg south of the angle of Conesus valley, at Websters, west of Marrowback hill, in Canadice valley on the south slope of Bald hill, and in the Honeoye valley. The upper Honeoye is choked for 3 miles with a continuous moraine, and at its head two ridges extend across the valley like dams. The west dam is 30 to 50 feet high, and is cut by Springstead brook not at its lowest point but at its highest (figure 1, plate 38). A much more massive and irregular dam a half mile to the east rises 140–200 feet above the valley floor. Both dams rest upon shale which is exposed between and below them (figure 1, plate 40). A similar moraine dam crosses the east fork of Bristol valley at Bristol Springs. In a fourth series belong the moraines of Frost hollow, Berby hollow, and the west fork of Bristol valley. The latter is choked with morainal mounds throughout its length of 4 miles. Of a little later date are heavy deposits in Bristol valley at the forks.

VALLEY-SIDE MORAINES

The presence of "quasi-lateral" moraines in the Canaseraga valley was noted by Chamberlin,* but he did not report their existence in the other valleys. Honeoye valley and West hollow are separated at their junction by High Point, a narrow precipitous ridge rising 1,000 feet above the Honeoye on the west and 600 feet above West hollow on the east (figure 1, plate 38). At the West Hollow level, between 1,400 and 1,500 feet, a rock terrace one-fourth of a mile wide and 2 miles long extends around

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*Third Report, U. S. Geol. Survey, p. 352.

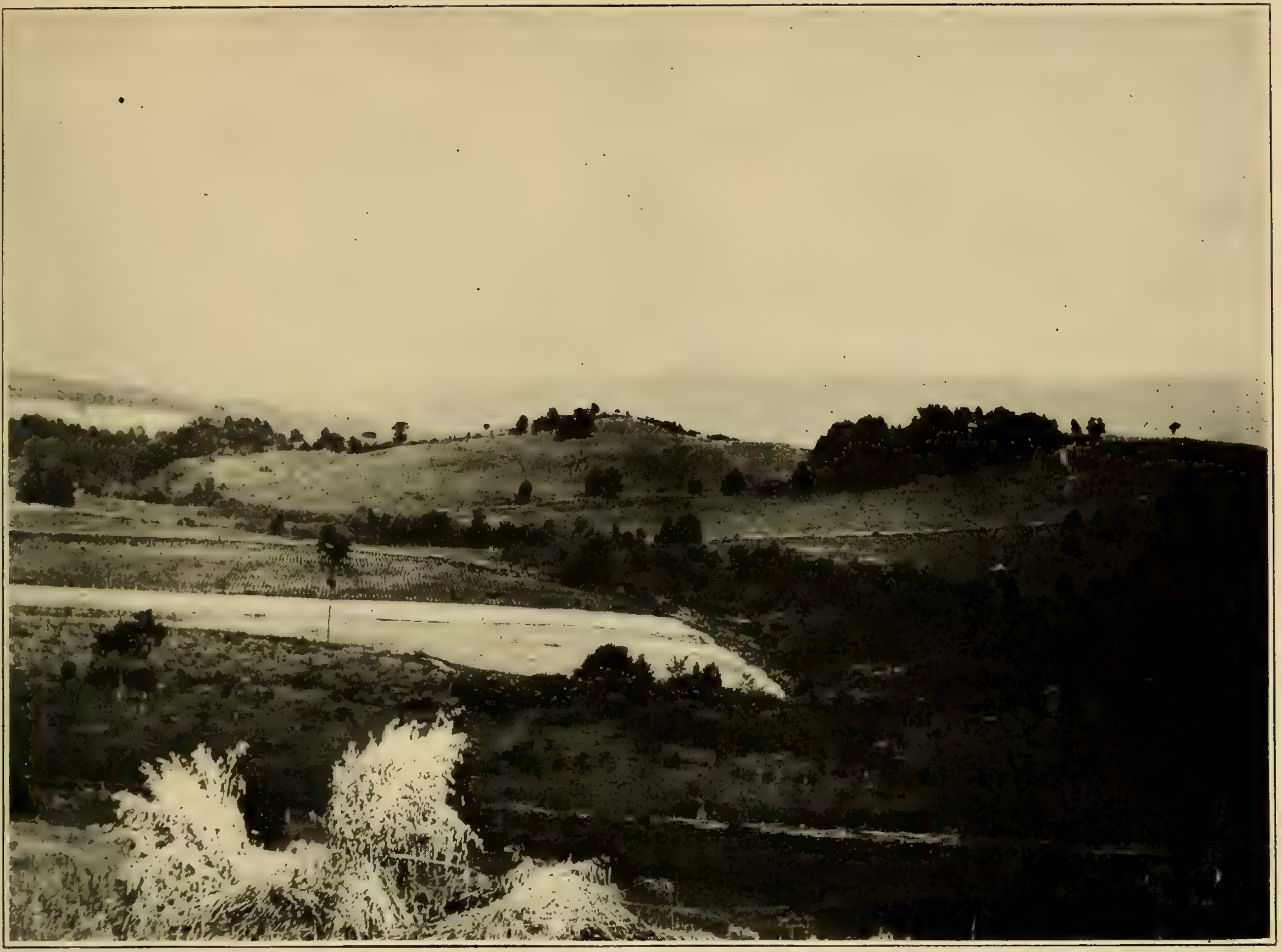

Figure 1.—Head of Honeoye Valley

View looking east from west moraine dam; east moraine dam in middle distance

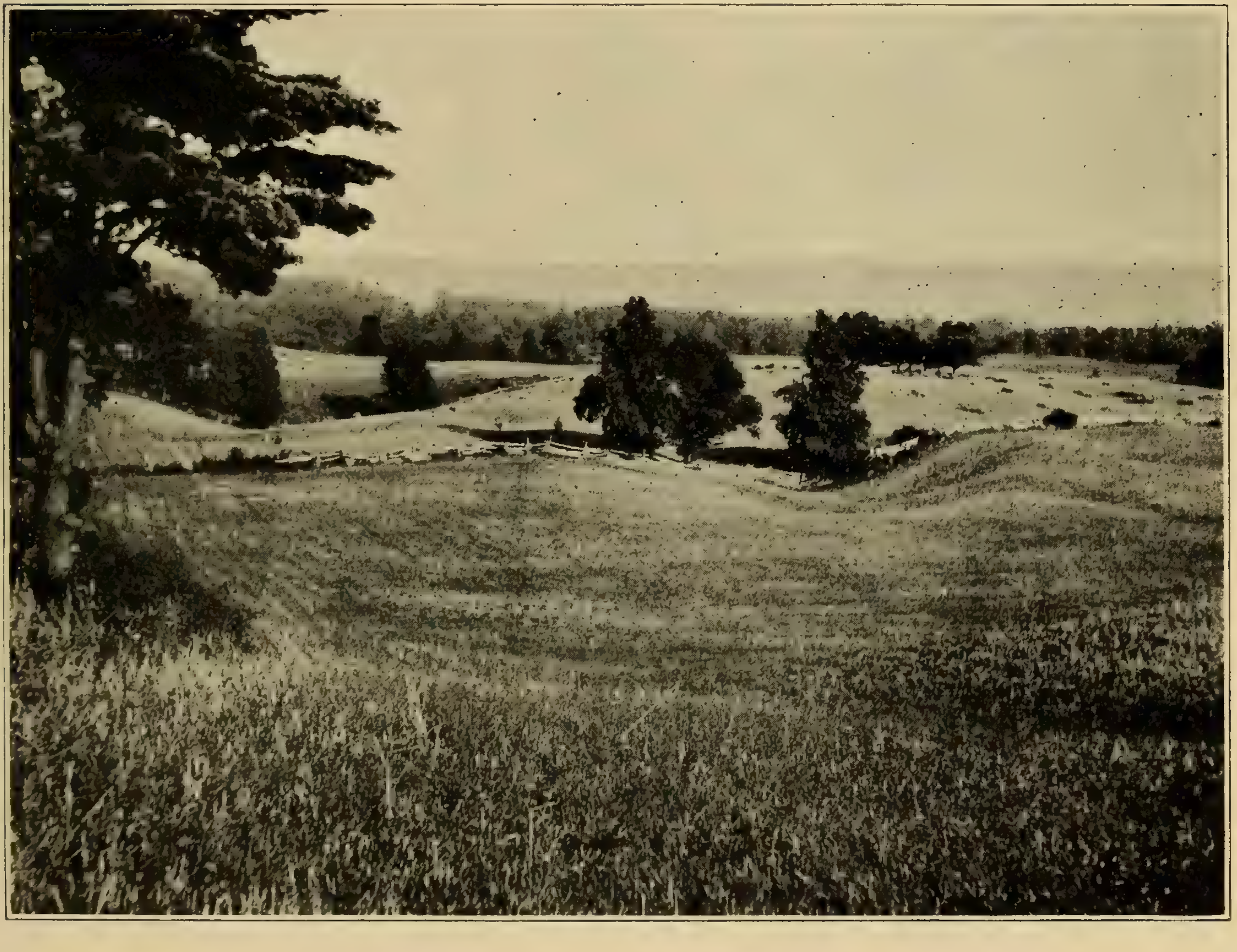

Figure 2.—Pitted Surface of High Point Moraine

HONEOYE VALLEY AND PITTED SURFACE OF HIGH POINT MORAINE

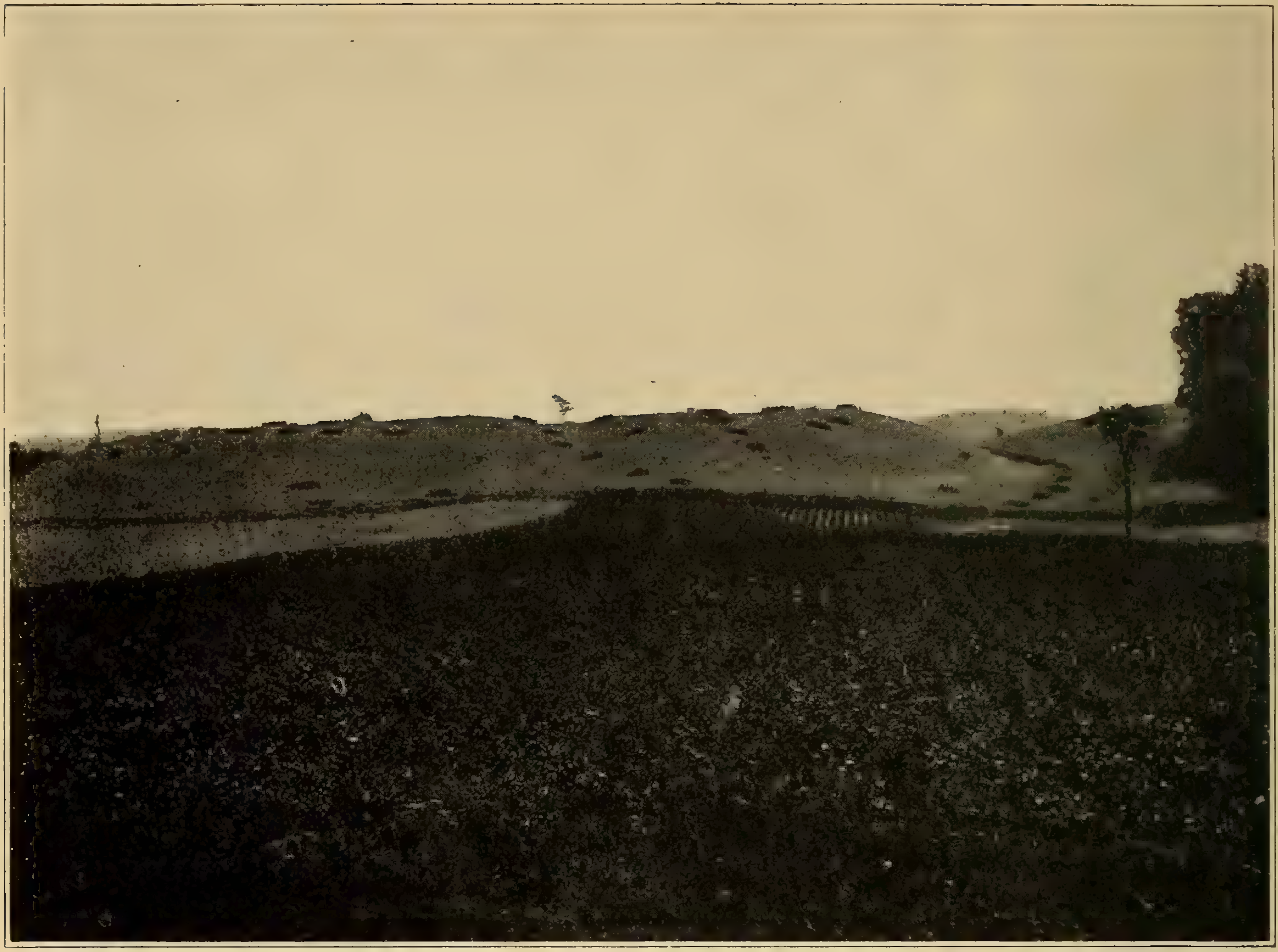

Figure 1.—West Slope of Nortons Delta

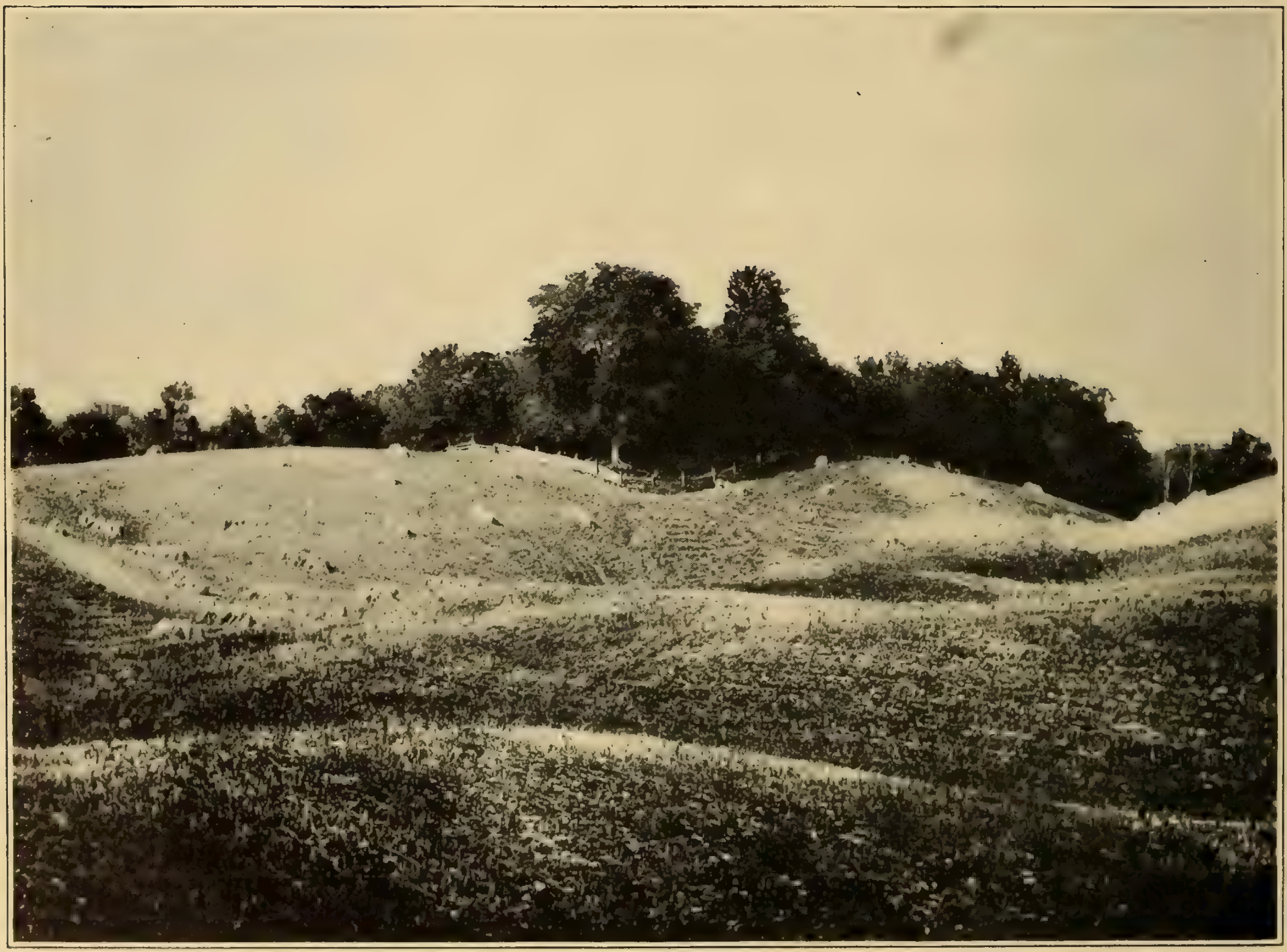

Figure 2.—Pitted Surface of Nortons Delta

NORTONS DELTA AND ITS PITTED SURFACE

the south and west sides, fitting into an offset in the valley wall like a shelf in the corner of a room. This shelf supports at a height 400 feet above the valley bottom deposits which present a morainic topography of a pronounced type. The material is largely sand and gravel with many crystalline boulders up to 5 or 6 feet in diameter. Mounds and sags of 40 feet relief and patches completely pitted with kettles (figure 2, plate 40) mark a well developed moraine which is continuous on the east with the outwash plain of West hollow. It was evidently the product of two distinct ice-streams which united at the south end of High Point. A small but perfect delta on Barker's farm, at the north end of the moraine, testifies to the existence of a temporary marginal lake. The moraine or "bench" is popularly known as "Hickory bottom," but I propose to call it the High Point moraine.

A similar terrace extends along the east side of Canadice-Hemlock valley for about 8 miles. At the north end, opposite the foot of Canadice lake, its elevation is about 1,500 feet, but it descends southward to 1,400 feet at the point where it joins the Hemlock valley-head moraine on a level with its summit. This slope may represent the dip of the strata. The width of the terrace is mostly a fourth of a mile, widening occasionally to a half mile, and at a few points disappearing altogether. It bears upon its surface a series of drift mounds, which mark the line of a fragmentary lateral moraine, 400–600 feet above the valley floor. Opposite the head of Canadice valley, where Nortons gull cuts across the terrace, a fine delta registers the height of glacial waters. Its upper level between 1,440 and 1,480 feet is a triangular area one-fourth of a mile on a side. Its margin on the north and west rises smoothly and steeply 60 feet (figure 1, plate 41). An especially interesting feature is the fact that at its apex an area of about 10 acres is completely pitted by a score or more of compound kettles, varying in depth from a few feet to 30 feet or more (figure 2, plate 41). On no other delta thus far reported is the presence of many stranded ice blocks so clearly shown. Nortons gull delta was built by a stream flowing from the land into a lake held between the valley slope and the margin of the ice lobe, and so near the latter that detached blocks of ice were incorporated in it during deposition. It is not a morainal or frontal terrace, but forms a distinct fluvioglacial species for which the name *morainal delta* seems appropriate.

GLACIAL LAKES

During the retreat of the ice the valleys of this region were occupied by temporary ice-dammed lakes with outlets to the south, the history of which has been outlined by Fairchild,* but not exhaustively studied.

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* Bull. Geol. Soc. Am., vol. 6, p. 353; vol. 10, p. 35.

During this period lacustrine sediments of unknown depth were deposited on the valley bottoms. To this filling is probably due the general flatness of the valley floors above and below the lakes and the absence of surface boulders at low levels.

DISCUSSION AND INTERPRETATION -

It is time now to attempt an interpretation of the peculiar features their history. On some points of the problem the solution seems clear and hardly open to question. Other points are difficult and obscure.

1. The absence of all indications of folding or faulting makes it certain that the valleys and ridges are due to erosion. The evidence is equally conclusive that they have been glaciated. The main problem, then, is to determine the part which water and ice have respectively played in their formation.

2. The hypothesis that this part of the Allegheny plateau was dissected in pre-Glacial times by northward flowing streams to a degree approaching maturity is the most obvious one. Their headwaters had eaten back beyond the crest of the plateau and interlocked with the headwaters of southward flowing streams. The Canandaigua stream would seem to have headed south of the terminal moraine at some point down the present Cohocton valley. A similar southward extension may be attributed to the Hemlock stream, and perhaps to the Canaseraga also.

On its face this hypothesis is met by one serious difficulty. The Cohocton-Wayland valley extends east and west a few miles south of the plateau crest, cutting across and connecting the heads of three principal northward sloping valleys, and is as wide as any one of them, but with a floor 500 to 600 feet higher. How much of this difference of level is due to glacial filling is unknown, but in the present hypothesis this valley seems incongruous and out of place. It may have been begun by tributaries of the Canaseraga, Hemlock, Canandaigua, or Cohocton streams—some or all of them; but that headwater tributaries near the crest of a plateau cut a valley a mile wide and 1,200 or 600 feet deep is a scarcely tenable proposition.

3. The scheme of Laurentian drainage in Tertiary times proposed by Grabau * postulates the Genesee river as a southward flowing consequent stream, and the Allegheny plateau as a cuesta through which it cut a gorge. On this hypothesis, the possibility that the Canaseraga-Cohocton valley is the modern representative of the Tertiary gorge of the Genesee is worthy of consideration. In that case the Conesus, Hemlock, and

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* Bull. New York State Museum, no. 45, pp. 37-47.

Canandaigua streams were southward flowing, consequent tributaries of the Genesee, and the Honeoye and Bristol streams were obsequent tributaries of a subsequent stream which occupied the Rush-Victor drainage channel. The southward convergence of the Canandaigua and Canaseraga valleys and the relations of West River valley to Canandaigua and of Conesus to Canaseraga are in consonance with this hypothesis, and do of themselves suggest that the drainage of the region was originally southward. This, of course, demands a glacial filling in the Cohocton-Wayland valley of more than 600 feet. A few deep borings in that valley would set this question at rest.

4. During the maximum extension of the Labrador ice-sheet this part of the Finger Lake region was 60 miles back of the glacial front, and was probably buried under several thousand feet of ice. During the late Wisconsin period of glaciation the ice-sheet became strongly digitate, and each north-south valley was occupied by an independent lobe, which endured long enough to build a terminal moraine of imposing mass, and in some cases valley-side moraines of smaller but notable bulk. The drainage from these ice-lobes deposited extensive outwash plains on the distal side of the terminal moraines. The conspicuously drumlin-shaped ridges and the U-shaped, oversteepened valleys are precisely such as characterize an ice-molded topography. Marrowback hill, Bald hill, and the basins of Hemlock and Canadice lakes might be taken as typical examples of the effects of glacial erosion on stream valleys and inter-stream ridges previously carved in soft and friable rocks.

The relation of Canadice valley to Hemlock as a hanging valley at both ends adds emphasis to the general expression of glacial sculpture. As the work of stream erosion alone, Canadice valley seems inexplicable. Whether it is assumed to have been originally the valley of a single tributary of Hemlock or to have been produced by the headwater erosion of two streams flowing from a midway divide, the small watershed and short course of such streams would have rendered them incompetent to erode a valley of anything like the present dimensions. The hypothesis that both Hemlock and Canadice valleys have been deepened and widened by ice erosion, but that Hemlock, lying directly in the line of ice-motion, was more profoundly modified, while Canadice was occupied only by a diverticulum of the glacial stream, would fairly account for their present forms and relations. In that case their present discordance of level, amounting to at least 250 feet, would furnish an approximate measure of the differential deepening suffered by the two during the glacial epoch.

All the evidence thus far discovered in the region under discussion points to the conclusion that the peculiar features by which these valleys differ from normal stream valleys are due to the work of glacial ice, and that during their occupancy by ice-fingers they suffered a deepening which may be conservatively estimated at 400 feet.

In the absence of opposing evidence, this conclusion seems almost too obvious to be debated. But since this paper was read Tarr has brought forward * evidence discovered by him in the Cayuga and Seneca valleys which opposes very grave objections to the theory of glacial erosion as generally applicable to account for the Finger Lake basins. In view of all the facts, the question must remain unsettled. More thorough and extensive studies may lead to the final solution of the problem.

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* American Geologist, no. 33, p. 271.

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NEW STUDIES IN THE AMMONOOSUC DISTRICT OF NEW HAMPSHIRE

BY C. H. HITCHCOCK

(*Presented before the Society December 30, 1903*)

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INTRODUCTION

In 1877 the writer published in the second volume of the Geology of New Hampshire a general description of the rocks of the Ammonoosuc district, the region extending from Woodsville to Lancaster, where the Connecticut river bends conspicuously to the west and has apparently annexed a part of Vermont to New Hampshire. The Connecticut has cut across a mountainous range in what is known as the Fifteen Miles falls, causing the drainage of the upper part of the state to unite with that of the Passumpsic river. On some other occasion I hope to revive an old theory, advocating the former drainage of the upper Connecticut through the lower Ammonoosuc to join the Passumpsic waters at Woodsville (Wells river, Vermont). Between these two valleys and the field of our inquiry there happens to be a fine development of Paleozoic strata with fossils, so that it is possible to know with certainty the age of a part of the sediments. The conclusions of the early report are not all sustained by our later studies, and I have thought it best on resuming the investigation of the geology to commence with the fossils, determine their names and horizon, and follow the beds into their associations with other rocks.

Fossils

AGE AND OCCURRENCE

The fossils from Fitch hill, Littleton, New Hampshire, were submitted to Mr Charles Schuchert, of the National Museum, Washington, who reports on them as follows: "The Littleton fauna is certainly middle Upper Siluric. The species suggest the Niagara, and there is nothing so recent as Lower Helderberg." *

Owing to the delay in preparing the manuscript of this paper, Mr Schuchert adds a later list † of the collection of the Littleton fossils in the National Museum, arranged according to their occurrence in the black shale or the limestone. In addition to those sent by myself, he examined those gathered by T. Nelson Dale several years since.

SPECIMENS FROM BLACK SHALE

Cup coral.
Favosites.
Leptæna rhomboidalis (Walcott's *Strophomena rhomboidalis*).
Strophonella cfr. *funiculata* (found among *Strophomena rhomboidalis*).
Conchidium cfr. *knighti* (*Pentamerus knighti* of Billings).
Rhynchonella (*Wilsonia ?*) (Walcott labeled it "allied to *Trematospira multistriata*").
Atrypa reticularis ?
Spirifer cfr. *sulcatus.*
Spirifer cfr. *plicatella* or *S. niagarensis.*
Pterinea cfr. *emacerata.*
Calymmene tail.
Dalmanites cfr. *caudatus* and *limulurus* (Walcott named it *D. limulurus*).

SPECIMENS FROM LIMESTONE

Stromatopora.
Halysites catenularia Linné.

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* From letter dated April 14, 1903.

† The date of this letter is May 11, 1904.

Syringopora with slender corallites.
Favosites, at least two species.
Conchidium cfr. *knighti.*
Gastropod related to *Polytrophis alatum* Lindström.
(See Pumpelly in Amer. Jour. Sci., iii, 35, 1888, pp. 79–80.)

SPECIMENS FROM LAKE MEMPHREMAGOG

Mr Schuchert has also examined a collection of fossils from Owls head, lake Memphremagog, about 60 miles to the north of Littleton. No Silurian species were found among them. He reports that they represent the typical Onondaga limestone fauna of the New York Devonian.

Mr A. E. Lambert, a graduate student at Dartmouth College, has made further collections of the Littleton fossils, and has furnished a description and photographs of the Dalmanites, which are appended to this paper.

THE TYPICAL FOSSILIFEROUS AREA

The best localities are within an area 7 miles long and 2 or 3 miles wide, from the north part of Littleton to the north part of Lisbon. Limestone is not well shown beyond the south base of Manns hill, and the old Clark and Burnham quarries are on what is sometimes called Farr hill. The associated rocks cross Manns hill into Dalton. I can not present a satisfactory section at the north end of the tract because of the existence of dislocations which are not understood. On the east there is a foliated granite, a mile and a half in width, reaching nearly to the Parker observatory on the top of Palmer mountain. This summit is occupied by slates, with a general northwesterly dip of the cleavage, which are allied to those to be mentioned farther south. Some of the strata are silicious. A mile west, on the ridge between the sources of Palmer and Parker brooks, the limestone appears, 60 feet wide where quarried, and carrying Favosites and crinoidal fragments. A sandstone flanks the limestone to the west. All the dips are about vertical. It is succeeded on the west side by an argillitic schist allied to hornfels.

The sandy rock is sometimes a well defined sandstone (a quartzite) and a partial or complete aggregate of crystals of quartz developed in a slate or in pure limestone. Because of the angularities it is somewhat analogous to the buhrstone used for millstones, and has locally received that appellation. On the whole it is probable that the band represents a single horizon, while it is easy to understand its origin from a sand, slate, or limestone. Imagine these rocks permeated by water carrying silica in solution. Crystals may form either by themselves or on grains of sand for nuclei, and the result will be a rock mostly composed of crystals. Sections across specimens of sandstone from Fitch hill show the secondary enlargement very much like that described from Wisconsin and elsewhere.* It is also conceivable that a part of what is termed "induration" may be the result of the deposition or interpenetration of strata by amorphous silica.

There seem to be two ranges of this sandy rock, coming near together on Manns hill, in the north part of Littleton, and diverging so as to appear on both sides of the Blueberry Mountain range, where they are disposed in a synclinal attitude. They are both represented in figure 1 of plate 42. This section extends from the village cemetery in Littleton along the Waterford road, past Fitch's house. At the east end the rock is a granite overlaid by the quartzite (*ss*), and then by the limestone before coming to Parker brook. A few fossils have been found in the limestone on both sides of the brook. After passing diorite the sandstone is again in evidence, both outcrops dipping westerly. The granite (protogene) crops out to the west of the sandstone, and also more abundantly near Fitch's house. Crinoidal stems have been found in thin bands of limestone in a slate quite near a fork in the road, and the rock is supposed to be a continuation down the hill from the fine exposures of fossiliferous strata represented in figure 2, plate 42.

The best fossil locality is near the residence of Mr Frank Fitch, about 2 miles west of the Littleton railroad station. The section through it, figure 2, suggests that the age of the coralline layers (1) is greater than that of the trilobite slate (2), while above them both are two other distinct bands of limestone—one quite pure calcium carbonate (3) and the other magnesian (4), neither of which contains fossils. The trilobite slate is calcareous and distinct from the argillite. The total thickness of these members must be from 200 to 300 feet. Above the limestones is a band of coarse sandstones (5), perhaps 25 feet thick. Hawes called it a "half fragmental quartz schist." As it contains both well rounded pebbles and enlarged mineral fragments, the term is not inappropriate. It is believed to be the equivalent of the sandstone, quartzite, or buhrstone previously mentioned. Still above the sandstone is a thick mass of argillite (6). On Fitch hill the amount is small, and it has been partially altered into a hornfels (novaculite) (7) because of contact with a diorite which occupies the summit of the hill and stretches on toward Kilburn's Rest for half a mile.

The section shown (figure 3) crosses Fitch hill a little to the south of figure 2. The order is the same as in figure 2, with the duplication of

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* R. D. Irving and C. R. Van Hise: Secondary enlargements of mineral fragments in certain rocks. Bulletin 8, U. S. Geol. Survey.

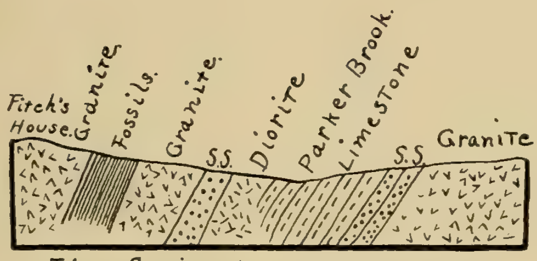
Fitch's House.
Granite
Fossils.
Granite.
S.S.
Diorite
Parker Brook.
Limestone
S.S.
Granite

Fig. 1. Section along Waterford Road.

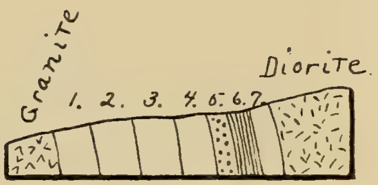
Granite
1. 2. 3. 4. 5. 6. 7.
Diorite.

Fig. 2. Fitch Hill.

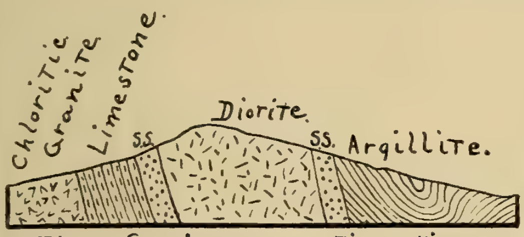
Chloritic Granite
Limestone.
SS.
Diorite.
SS.
Argillite.

Fig. 3. Section across Fitch Hill.

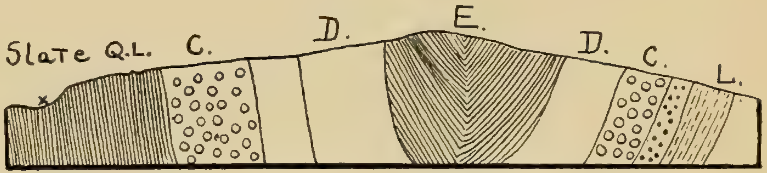
Slate
Q.L.
C.
D.
E.
D.
C.
L.

Fig. 4. Section across Blueberry Mountain.

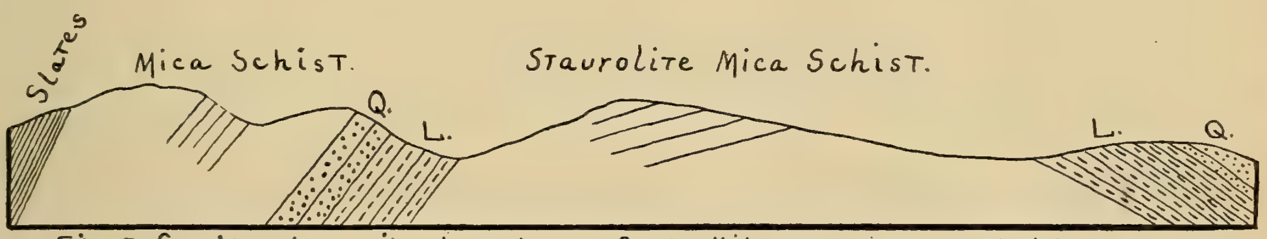
Slates
Mica Schist.
Q.
L.
Staurolite Mica Schist.
L.
Q.

Fig. 5. Section three miles long from Sugar Hill towards North Lisbon.

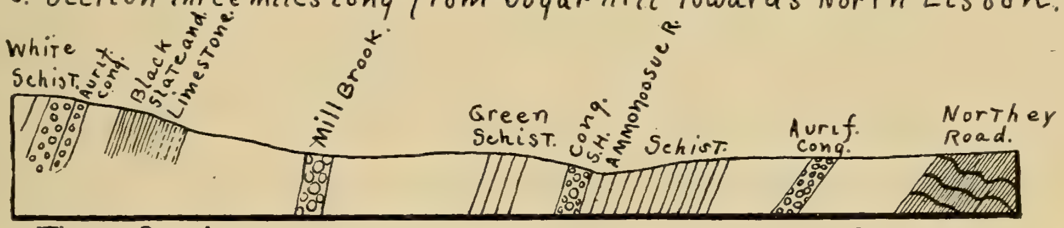
White Schist.
Aurif. Cong.
Black Slate and Limestone.
Mill Brook.
Green Schist.
Cong.
S.H.
Ammonoosuc R.
Schist.
Aurif. Cong.
Northey Road.

Fig. 6. Section across Ammonoosuc Valley at Salmon Hole Brook.

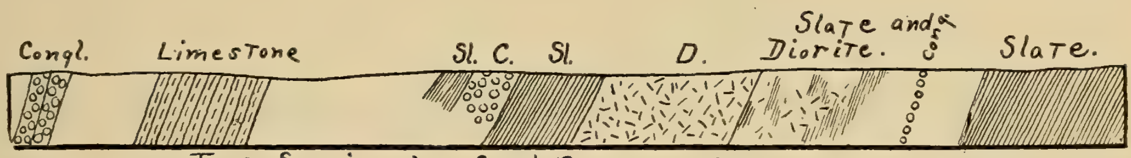
Congl.
Limestone
Sl.
C.
Sl.
D.
Slate and Diorite.
Cong.
Slate.

Fig. 7. Section along South Branch of Ammonoosuc.

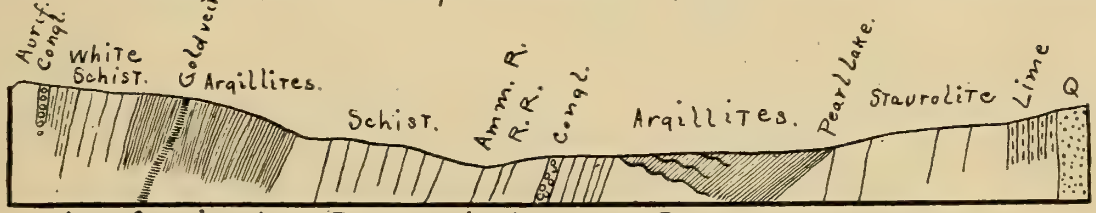
Aurif. Cong.
White Schist.
Gold vein
& Argillites.
Schist.
Amm. R.
R.R.
Congl.
Argillites.
Pearl Lake.
Staurolite
Lime
Q

Fig 8. Section from Bronson Hill, Lisbon, to Parker Hill Lyman.

S.H. Wilkins, del.

GEOLOGICAL SECTION IN THE AMMONOOSUC DISTRICT, NEW HAMPSHIRE

the sandstone (*ss*) and the addition of a synclinal of slates at the eastern base of the hill.

The Blueberry Mountain range extends from Fitch hill southerly through Littleton, Lisbon, Lyman, and Bath and is a mass of argillite with a synclinal structure throughout. A typical section, figure 4, plate 42, is that from the slate quarry across to the Ammonoosuc, about 2 miles southerly from the fossils in the Fitch pasture. It shows the fossiliferous limestones at the base on both sides (*LL*) overlain by sandstone and conglomerate (*CC*) and two kinds of slate, the lowermost (*D*) being very black and the other (*E*) drab, with a total thickness estimated to be 1,500 feet. Layers of grit alternate with some of the slates. The basal parts of the argillite carry a coarse conglomerate to be described later.

Taking the Blueberry Mountain range as a whole, it may be said to commence in Bath, has been cut deeply in Lyman by Smith brook and Mill brook, and shows a more decided gap just north of Fitch hill, having been eroded by a branch of Parker brook, which has removed nearly all the slate. Considered as a continuous elevation, the range should connect with the Dalton mountain, but deep erosions on both sides of Manns hill exhibit other rocks than slate. The topography of the northeastern part of the range is shown on the Whitefield quadrangle of the United States Geological Survey.

The fossils characterize only the basal limestones, which are middle Upper Silurian. There is certainly enough thickness of strata in the sandstone, slates, and conglomerate superposed on the limestones to suggest at least the residue of the Upper Silurian, and perhaps the Devonian. Rocks of similar petrographic character may be followed down the Connecticut valley into Massachusetts (including Bernardston), a distance of 150 miles, where Devonian fossils have been recognized. Fossils of this age adjoining lake Memphremagog have been mentioned above, 60 miles distant, but in a parallel basin. That horizon is higher than anything known in northern New Hampshire or Vermont.

Igneous Ejections

Omitting for the present the description of a complex series of schists adjoining the Blueberry synclinal, reference must be made to a different class of rocks. It may be truthfully said that this synclinal in Littleton rests on igneous materials. Below and in contact with the fossils on Fitch hill the rock is a chloritic foliated granite (protogene of Hawes). Above the fossils it is a coarse diorite which has converted the slate into hornfels. Along the east base of Blueberry mountain are lenses of hornblende schist. Sections to the north of Fitch hill would illustrate the presence of other igneous rocks.

These eruptive rocks, being misunderstood in our early studies, caused us to announce what now seems to be very singular conclusions. Our teachers had taught us to believe in their sedimentary origin. Diorites, diabases, and protogenes were simply altered sediments, and were relegated to a different class from the truly igneous masses of the same names, with the convenient prefix of *meta.* Thus a *metadiorite* was not to be thought of as being an igneous mass, but a metamorphic schist, having the same minerals with its congener. The presence of foliated planes indicated stratification. The influence of this theory seems to have affected the opinions of Doctor Hawes, whom I employed to write up the lithology of the New Hampshire rocks. My advisers, however, disagreed as to the age of these schists, the one class referring them to the Huronian (the original "Quebec group"), and the other to the higher place indicated by the fossils. I now regard the foliated schist as truly igneous.

It should be remarked that I am not speaking of the green schists extending through the middle part of Vermont between Canada and Massachusetts, but only of the Connecticut Valley range, which widens very much in the northern part of New Hampshire; and it is an interesting circumstance that when one wishes to understand the petrography of these crystallines he must consult the descriptions of the original Huronian rocks about lake Superior. It was perfectly natural for those who were observing the similarity between the eastern and western schists to believe them to be of the same age. Possibly the tables may be turned some day, and a portion of the schists now called Algonkian may be proved to be Paleozoic.

Little need be said of an outcrop of augen-gneiss or porphyritic granite in the corners of the towns of Littleton, Bethlehem, Whitefield, and Dalton. It is the most northern area of that rock in the state, and there are no facts at present known to make clear its relation to the modern groups. It does not seem to have sent out branches into the adjacent formations.

A somewhat triangular area of granite, both massive and foliated, lies westerly from the porphyritic variety. It contains occasionally inclusions of schist in its western part. It is doubtful whether it extends easterly into Bethlehem, as represented on the state map. It is more closely allied to the chloritic granites on Parker brook than anything else.

The most extensive granitic area is that called in the report Bethlehem gneiss or protogene. A characteristic variety, identical with the "epidotic mica gneiss" from Lebanon, is number 38 of the educational series of rocks described in bulletin number 150 of the United States Geological Survey. It comes from another area, but both rocks are the same in composition and appearance. The epidote is common, but not universal. The Bethlehem area extends easterly into Whitefield and Jefferson, and is very commonly foliated. It narrows to a point in North Lisbon, and seems to have cut off the northeastern extension of the Paleozoic strata of the Ammonoosuc district. The foliated planes have an average dip of about 70 degrees north 30 degrees west. Were it not for abundant inclusions of mica schist, one would be inclined to retain the old name of gneiss or schist for the group. The fragments are particularly abundant in the western part of the area, which, as will be seen readily on the geological map, plate 43, is to a certain extent coterminous with the apparent place of the schists that have been absorbed by the igneous intrusions. Portions of the mass may be the original slate thoroughly interpenetrated by an igneous paste, but it has been so changed that it more closely resembles the granite than the original strata.

HORNBLENDE ROCKS

These do not cover large areas, but are quite common, and of too small extent to be represented on the map. The most important is on the Ammonoosuc, above the village of Lisbon, following up the Oregon road toward the argillite. Smaller patches are common in the Lisbon-Swift water complex, and supposed to be of igneous origin. There are besides many crystalline schists containing hornblende or actinolite needles of secondary origin.

A sample of a dike cutting and altering the slates at North Lisbon was submitted to Mr W. C. Phalen, who reports as follows:

> "Number 2.—This rock has a schistose structure, and there is evidence of its schistose nature even in the thin-section that has been studied. Hornblende needles in abundance, brown mica, magnetite, quartz, and feldspar constitute the major portion of the rock, which might appropriately be termed an amphibole schist."

This report is of value because, in connection with the observed phenomena, it seems to be proved that the hornblende schists of this district are of truly eruptive origin, and that the date of their ejection is posterior in time to the age of the slate. The hornblende schist seems to be allied to diorite rather than to diabase.

CONTACT PHENOMENA—LYMAN SCHIST

Quite a large class of rocks have been affected by these igneous intrusions, which were not well understood at first, for the study of the famous Mount Willard locality by Doctor Hawes was not undertaken till after the close of the survey. He had described a curious rock quite near the fossils on Fitch hill under the name of novaculite, which resembles the hornstone of the White Mountain notch. It is a light gray, massive, homogeneous material resembling felsite, and, like that, fusible before the blowpipe. As studied microscopically, it is found to be an excessively fine grained mixture of much quartz, little orthoclase, minute mica films, and grains of calcite. This compact rock, which originally was slate, is so limited in amount on Fitch hill that no one can doubt its origin from contact with diorite; but there are many square miles of similar rocks in the district which would be referred to a similar origin were it possible to believe the thermal influences could have been so widely extended. In my report I gave a local name to this material—Lyman schist—and several ranges of it can be described. Doctor Hawes speaks of it as identical with the novaculite, using the general name of argillitic mica schist. It is composed of fine quartz, feldspar, mica, chlorite. and various accessories. With much chlorite the color is green, and a preponderance of the micaceous ingredient gives it a soapy feel. The phyllites and mica slates belong to the same group. A careful analysis by Hawes indicated that the sample tested had the composition of an ordinary clay minus the larger part of the water, but he regarded the mass as made up of recrystallized minerals, not fragmental. Still it is a connecting link between argillite and mica schist. This does not necessarily mean that the schist was not of fragmental origin—only the primitive character has been obliterated.

I have found many cases where the original fragments are still recognizable. One is in certain parts of the distribution of the "auriferous conglomerate." The pebbles show unmistakably on the smoothed surfaces of the ledge, but when cleaved the interior has the perfectly foliated structure of argillitic material. Even the silica has become a silicate. Some of these rocks weather so as to show pebbles several inches long, but every pebble is of the same hornfels as the entire mass when the structure has been obliterated. All these homogeneous rocks weather extensively, so that they can be recognized at once by their light color. We called them the "white schist" when in the field.

In Littleton there is a band of these white schists adjoining on the west side the chloritic granites and slates. In Lyman it seems to merge into a very coarse conglomerate, entering the town on the east side of Partridge lake, and it is also a prominent rock on Mormon hill. The high land east of Parker hill (Lyman P. O.) shows the same rock, and it continues, partly covered by argillite, to the extreme southern end of the district at Woodsville. There is a repetition of these argillitic schists, accompanied by other rocks, in the south corner of Lyman and the west part of Lisbon—probably a large faulted block—raised from below.

These argillitic schists, like hornfels, seem to have been produced by a widespread thermal agent, corresponding to igneous masses in contact with earthy materials. Whether to say the igneous mass lay near enough the surface to produce contact phenomena or to call the process "regional metamorphism," the result is the same. Materials of originally diverse aspects have been reduced to a homogeneous paste. Hence in mapping the distribution of this altered rock it must be borne in mind that it may represent more than one original.

DISTRIBUTION OF THE LIMESTONES

It will now be possible to trace out the distribution of the fossiliferous limestone series. The typical section indicates that besides limestones there are dolomitic and slaty layers, which are often ferruginous. Because of the alterations, fossils may not be widespread or distinct very far away. The best showing is the line of outcrop on the west side of Blueberry mountain. All through Littleton and into the north corner of Lisbon the limestone with distinct corals constantly shows itself, usually in a valley. The depression may be followed to the height of land back of Bald hill in Lisbon, where the continuity is obscured by a thick blanket of till. Another valley succeeds with the same trend toward Youngs pond, but no ledges are visible till half the ascent to the next watershed has been reached. Here in abundance are the friable shales, which continue to the top of the hill (called Knapp in the report), where several large layers of limestone appear, carrying obscure corals and fragments of small crinoids. I do not wish to assert an absolute continuity of extent from the last seen coralline ledge in the north corner of Lisbon, but the same formation with its fossils is present along the line of strike. There is here a new association. On the west side is a strong band of the auriferous conglomerate, and the course of this band has been traced with exactness into Bath. The slates accompany this conglomerate throughout, and seem to lie upon both sides of it. The harder rock makes sharp bends, and the calcareous slates conform to them. A good illustration is at what has been called the Dow ledge on Smith brook in the south part of Lyman. The conglomerate lies at the south foot of a high hill, and has been so bent as to form an acute angle. Limestone bands adjoin it, displaying satisfactorily both the planes of cleavage and of stratification, conforming to the harder strata. The slates have a larger development farther south in Bath, where both kinds of divisional planes are distinctly displayed. Many additional details might be given, but it would require the use of maps of a large scale to render the delineation effective.

On the east side of Blueberry mountain the line of limestone outcrop can be traced, but less satisfactorily. One is represented in figure 4, plate 42. Between this point and Mill brook the rock has not been seen for a distance of 4 miles along the line of strike, in an unfavorable region for observation. At North Lisbon, away from the proper line of outcrop, it is found plentifully, as will be described later. South from Mill brook the limestone with crinoidal fragments has been observed, with the accompanying black slates and auriferous conglomerates, as indicated by figure 6, plate 42. These outcrops are connected with the faulted block of argillitic schist, and in the very south corner of Lyman, extending into Bath, are continuations of all these different kinds of rocks.

The limestone at North Lisbon is situated along a different line of strike. Commencing near the railroad bridge below the station, it is finely developed and extends down the Ammonoosuc river for about 2 miles. The rock is white and carries large crinoidal fragments. A dike of diorite, number 3 of Phalen's determinations (see beyond), cuts this ledge. Near the mouth of Walker brook are hornblendic layers, suggestive of a metamorphic change sometimes observed in calcareous material. The importance of this range may appear in the fact that erosion has been deeper here than along any other of the calcareous lines of outcrop. Sandstones or quartzites accompany this range.

To the east there is a still stronger calcareous band. It starts near the south branch of the Ammonoosuc, about a mile southeast of Streeter pond, and follows a northeast and southwest road past the "central" school-house of Lisbon nearly to Salmon Hole brook. It underlies an equally important band of quartzite, both dipping toward the Ammonoosuc.

This duplex calcareous and silicious range is of even greater thickness in its last known development farther east, from the old iron furnace of Franconia past Sugar Hill village into Landaff, where the limestone disappears, but the silica connects with the Coös quartzite of my report, a formation traceable through New Hampshire into Massachusetts. Limestone of considerable thickness is associated with it in Haverhill, Orford, Lyme, and Plainfield. Through Lisbon the limestone usually dips easterly beneath the quartzite, though there is a synclinal at Bronson's quarry.

Thus there are five parallel bands attended by sandstone, quartzite, or conglomerate. Three of them carry fossils, including the one affording the characteristic middle Upper Silurian forms. It is reasonable, therefore, to suppose that all of them are of approximately the same age.

Figure 5, plate 42, is a section illustrating the positions of the two eastern ranges, *L* and *Q* representing the limestones and quartzites. I do not know whether the staurolitic mica schist between the two limestones is of inferior age. The staurolite crystals are profusely abundant and furnish both the red and black varieties known as from Mink pond (now Pearl lake), in Lisbon. The natural continuation of metamorphic influences might enlarge the slender staurolites of the upper slate. This area in the east part of Lisbon is represented on our map. Similar rocks to the south of this district have been described as newer than the quartzite.

The Conglomerates

First of all is the one termed "auriferous." My attention was turned to it in my very first visit to this region in 1868. Being very durable, it has resisted disintegration, and its stratification marks are well preserved, so that it is a safe guide to the stratigraphy of the district. The pebbles in it are chiefly of quartz, commonly less than an inch in diameter; rarely the material is of jasper, chlorite, or hornfels, the fragments having a maximum breadth of 2 inches. In some localities the pebbles have been elongated, flattened, and distorted, and I have mentioned instances where they have been fused into a homogeneous schist. A small amount of gold has been proved to exist in it in certain favored localities, whence the name, and the thickness is usually 100 feet. The narrowest is 10, and when it reaches 300 or 500 feet there is a suggestion of duplication by folding. Over the principal area of distribution it is always found on the hilltops, because of its greater durability.

The part which is truly characteristic and uniform commences abruptly in Lyman, southwest from Youngs pond, and may be traced into Bath about 5 miles, in 2 lines. A faulted segment of the same, repeated, extends equally far to the north, reaching to Mill brook, but it does not extend so far south by a mile.

The areal distribution of this formation illustrates the nature of the forces which have variously disturbed its original continuity. As a rule, the dip is nearly vertical; the continuous band has been broken into many segments, most of which have been curved or faulted, or both. Apparent discontinuity may sometimes be the result of a drift covering. Not only is the conglomerate itself thus disarranged, but the associated formations must be similarly affected to a considerable extent. Segments may be pushed out of line by the presence of some refractory mass on one side, and every kind of orographic movement may be looked for. The result of the disturbances is the existence of a gigantic breccia, or mosaic, whose pieces may not be firmly cemented together. Curved strata will prevail until the strength of the rock gives way, and in many cases the crevasses have been conspicuously filled by veins of white quartz. It is as easy to determine the original line in the formation as to recognize the outline of a chimney that has fallen down.*

The language descriptive of the fragmental condition of the crust of the earth in the Ammonoosuc district is also applicable to the crystalline and Triassic areas of the southwest part of Connecticut,† according to Professor W. H. Hobbs. He finds the fractures correspond to several systems of joints. The two regions may be said to correspond in respect to the origin of the mosaic structure, but the displacements have been greater apparently in the more northern district.

OTHER CONGLOMERATES

Secondly, there are other conglomerates of a very puzzling character. The abrupt termination of the auriferous conglomerate at its northern end south of Youngs pond has been mentioned. Its place is taken, nearly along the line of strike, by a coarse mass almost suggestive of till because of the miscellaneous arrangement and size of the fragments of green and white schist, some attaining 2 feet in length. It may be followed for 3 miles to the edge of Littleton, passing to the west of Mormon hill, which is also full of conglomerates. Slate, conglomerate, and argillitic schist are so intermingled that often any one of the three might be considered as a lens imbedded in the mass of either of the two others. These conglomerates dip southeasterly toward Blueberry mountain, at whose base is another mass of rounded fragments called familiarly by us the "egg conglomerate," some pieces attaining the size of an emu's egg. The two may possibly run into each other.

Still another conglomeratic group follows the course of the Ammonoosuc river between the villages of Lisbon and North Lisbon for 5 miles. The first one underlies the bridge at North Lisbon. The pebbles in it are white and blue quartz, hydromica schist, two or three gneisses, slates, calcareous bits, with an argillo-micaceous paste. The source of the handsome grains of blue quartz is unknown. Some pebbles are a foot long, some have been bent, flattened, and distorted. The dip is 65–70 degrees north 22 degrees west. A similar rock with friable cement crops out opposite the mouth of Walker brook on the east side of the river adjacent to a hornblendic mass. It is more strongly developed on the west side of the hornblende at the W. K. Chase house of the county map (or G. Conrad of D. H. Hurd and Co.'s atlas), and is continuous to the school-house at the bridge over the Ammonoosuc near the railroad. In front of W. Bishop's house the pebbles have been very handsomely pressed out of shape. An exposure at J. Hastings, in Bath, may belong to this series, situated near the middle Upper Silurian rocks and dipping to the northwest.

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* For a good map of these disturbances see Geology of New Hampshire, vol. 2, p. 296.

† Bull. Geol. Soc. Am., vol. 13, and also the present volume.

Figure 6, plate 42, represents a section from the Northey road on Salmon brook across the Ammonoosuc and up Mill brook on which three important conglomerates are indicated, the first the probable equivalent of the "calico rock," the second at the school-house by the bridge, and the third another mass near a trout-hatching establishment, where a new road passes down the west side of the river. Just north of the village of Lisbon and at the bridge over the river in the village, as well as farther north, are other outcrops of these conglomerates.

The last important conglomerate is represented on our section, figure 7, plate 42, 1,100 feet east of the North Lisbon bridge, and has been identified across the valley of the south branch. It contains, besides the materials mentioned beneath the bridge, pieces of soft mica schist. From fancied resemblances it received the field name of "calico conglomerate."

At first it appeared reasonable to correlate the auriferous conglomerate with related material upon Salmon Hole brook, the Landaff gold mine, and farther south. Further reflection suggests that this line of outcrops on the east side of the Ammonoosuc should be considered as the continuation of the calico conglomerate of the south branch. The Landaff rock is more like the auriferous than the other conglomerate, but we can not insist upon close correlations of coarse sediments from superficial resemblances. An apparent stratigraphic line must have a stronger determinative influence than a uniform texture.

The end of this line of conglomerate is only 2 or 3 miles distant from a range of quartzite which is often composed of coarse constituents, and the two are made to look toward each other by the occurrence of a related rock in the valley of Mill brook, Landaff, to be specially mentioned later. The eastern range is the Coös quartzite of the published report, now traceable from Sugar hill (figure 5, plate 42) southerly through the state. To correlate these two silicious formations it is not necessary to find a surface connection, since a continuation could be effected by means of a fold—probably a synclinal—beneath the eastern area of argillite terminating at Pond hill in Landaff.

It was stated that the "egg conglomerate" occupies a place near the base of the Blueberry Mountain synclinal of argillite. The "calico" rock is near the border of the eastern argillite range, soon to be mentioned. While it is difficult to adjust the dips, the geographic positions suggest a correlation which will include the majority of all the conglomerates; they may belong to the same horizon near the base of the argillite. This suggestion may be confirmed by the presence of pebbles or inclusions of slate. I have noted this fact specifically in the auriferous conglomerate on Smith brook in Lyman, in the conglomerate near Mormon hill, and remarkably large pieces in the Coös conglomerate in the north edge of Landaff (Baptist church). The schist inclusions at North Lisbon may have come from slates. All the conglomerates, except those farthest east, abound in fragments of the white Lyman schist. The green Lisbon schists occur sparingly.

It seems proved, therefore, that all these conglomerates are closely related to one another. Stratigraphically they overlie the fossiliferous limestone of the middle Upper Silurian, and also the sandstone of Fitch hill, from which last they are separated by a few feet of argillite.

Areas of Argillite

Enough has been said of the Blueberry Mountain main range of argillite—a possible Siluro-Devonian basin, extending from Bath to Littleton, 20 miles. It is traversed by veins of auriferous quartz. At an artificial tunnel in Lyman this rock has been pierced for nearly 700 feet, and gives as much evidence of disturbance by folding and faulting as the auriferous conglomerate. I can not find marks of strata distinct from those of cleavage. At two localities there is a resemblance to ribbons of color produced by a minute bending and faulting. At Kilburns rest in Littleton the slates have been shattered as if by a crusher, and the fragments reunited by some sort of adhesion. Other ledges have been faulted slightly since the ice age. Crystals of staurolite are wanting in this area, though small garnets are sometimes seen. In my report I made the presence of staurolite indicative of a difference in age. It seems to be generally believed that this is not a necessary distinction, because the secondary minerals may be developed by metamorphism. If so, the next argillitic area to be mentioned, on the east side of the Ammonoosuc, must be regarded as a repetition of the first. It is 7 or 8 miles in length, less mountainous, cut deeply by the south branch, terminated at the north end by the great eruption of Bethlehem granite, and, after continuing through Lisbon, ending in Landaff like a synclinal. It was called Coös slate in the report. It is easy to find at several localities clear evidence of banded strata crossing the cleavage planes at right angles. While the cleavage planes dip generally from 60 to 70 degrees to the north of west, the strata at the western edge of the argillite dip from 25 to 30 degrees southeasterly. One locality is along the gulf road from Lisbon to Breezy hill, and another at the crossing of Salmon Hole brook, by the carriage road, a mile east of the Sugar Hill railroad station (see plate 42, figure 6). Slender staurolites are found in it west of Pearl lake, and especially at a bend in the south branch, 3,000 feet east of

North Lisbon. Multitudes of small garnets accompany the staurolites, and in several ledges the garnets exceed 1 inch in diameter, accompanied with large patches of masonite or chloritoid. There are very few outcrops of the slate north of the line of the south branch, so that the details of this section, as shown in plate 42, figure 7, are important, illustrating the presence of erupted dikes and their effect upon the sediments.

Under the bridge at North Lisbon lies the conglomerate already described. For 600 or 800 feet to the east along the river no ledges are visible, but the thick, white, fossiliferous limestone a few rods to the south must represent the rock in place. On the north side there is an outcrop of argillite supposed to lie east of the limestone along the line of strike, and it is the first rock seen on the river's bank, 1,100 feet from the bridge, with a dip of 45 degrees north, 32 degrees west. I think it partly calcareous. Next is the calico conglomerate, 80 feet thick, having a dip like that of the slate. To the east the slates appear again, with higher dips, and disturbances produced by dikes of diorite (number 2 of Phalen), which has silicified the sediments by contact, changing it into a quartzite. These altered strata are about 55 feet wide, including the diorite. Following these are in order 50 feet of slate not much altered; a diorite dike 30 feet wide (number 4 of Phalen) filled with nodules very similar to the elliptic bunches described by J. Morgan Clements in the Vermilion iron-bearing district of Minnesota * and by him correlated with the pseudo-bombs of the Aa lava of Hawaii.

The thickness of the slates seen along the bank to this point amount to 146 feet. Next succeeds another diorite 304 feet wide. After that no rock is visible for 50 feet, and then there are 165 feet of silicified slates, followed by another Aa diorite 20 feet wide. Then follow in order 30 feet of slate, 85 feet of diorite, 20 feet of indurated conglomerate, accompanied by hornfels with altered slates for 320 feet. Beyond this point the slates are more nearly normal up to 2,600 feet from the bridge. The ledges become steep cliffs for an eighth of a mile farther, and there is an elbow in the course of the stream, where is the locality of the large garnets and chloritoids.

These details were obtained in 1903. The locality was visited earlier by Doctor Hawes, who was especially interested in the diorite or amphibolite, number 215 of the New Hampshire special collection. Other specimens obtained from this section are numbers 152, 231, 232, 234, 235, and 245. That the diorite is not an altered sediment is proved by its actual presence in dikes, its Aa structure, and by the production of contact phenomena. Why Doctor Hawes and myself should have both failed to recognize the igneous nature of the diorites is singular, but our

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* Monograph XL of the U. S. Geol. Survey, 1903.

minds were preoccupied with different theories for their origin. We had accepted the view of the presence of older crystallines, and the phenomena seen along the stream were explicable on that theory. These diorites are more abundant to the north of the section near Streeter pond, but have not been seen farther south because of an extensive covering of the rocks by drift.*

LISBON-SWIFTWATER COMPLEX

In the state report the local name " Lisbon " was applied to the green schists, and " Swiftwater " to an indefinite group of mica schists, slates, and conglomerates, both making parts of one whole. For convenience in description the double name may be employed, it being understood that the fossils found in the limestone will give character to the whole, though they have not yet been seen in the southern portion of the area.

More particularly the Lisbon rocks are green chloritic schists and sandstones, igneous diorites, granites, and protogenes, at first thought to be stratified; hydromica schists, quartzites, limestones, conglomerates, etc. The Swiftwater rocks are mica schists, quartzites, hornblende schists, slates, argillitic and sericite schists, and obscure conglomerates. These two groups were separated from each other on the published map, but further explorations indicate that none of these rocks are restricted to any particular horizon. The last named series seems to underlie the other. At the northern end of the district the Coös group was distinguished from the other, but our later studies would indicate that these quartzites and mica schists, with others of an argillitic character at this locality, belong to the same general Paleozoic Lisbon-Swiftwater complex. The greater breadth of the southern part of the complex may be due to duplication by folding.

The quartzites of Littleton seem to be silicified mica schists and merge into the strata connected with the limestones on Manns hill. The formation of the broad valley in which the village of Littleton is situated has removed or concealed the ledges by alluvial deposits, but their continuation to the south is evident on Walker hill, in Lisbon. A characteristic whetstone mica schist is traceable from South Littleton across to the well known quarry in the north part of Lisbon. All these rocks underlie the coralline limestone.

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* Three varieties of the rocks from this section were sent to Professor G. P. Merrill for determination, who turned them over to Mr W. C. Phalen, who sends the following descriptions:

Number 2 already quoted, page 467.

"Number 3 is practically the same as number 2, so far as constituents go. There is a good development of plagioclase, and for that reason the rock might be classed as diorite." (Mentioned on page 470.)

"Number 4, principally fine grained aggregate of amphibole and feldspar, and may appropriately be called Lamprophyre if in dike form or a diorite if in massive form."

In passing from North Lisbon in a northerly direction over the hills, the granite (Bethlehem) reaches nearly to the top of what may be called the north Walker hill, and it has evidently increased the tilt of the strata by its protrusion, and has silicified the adjacent schists. Sericite schists and a sprinkling of hornblende crystals in other strata come next, followed by a chloritic conglomerate with flattened pebbles, which may be located at the intersection of the town line by a carriage road. To the west is a considerable mass of diorite before reaching extensive argillites forming the eastern flank of the Blueberry range.

Going west from North Lisbon, the limestones are overlain by sandstones, the conglomerate under the bridge, drab quartzites and mica schists carrying scant calcareous strata, all dipping about 50 degrees northwesterly. Then for half a mile no ledges are exposed, because of the presence of the south Walker Hill morainic mass. Then may be seen slaty rocks, including the well known whetstones, a fourth of a mile wide, with a smaller inclination. The last mile of this section to the Blueberry slate range is mostly taken by green chloritic schists and an igneous mass of hornblende.

The next section, up the Whipple brook on the "Oregon road," discloses only hornblende rock, with some limestone at the start, most of the rock being covered by the quaternary floodplain. It is presumed that some of this hornblende schist may have been altered from limestone, and thus not have been originally an igneous rock.

The next traverse across the complex lies along the courses of Salmon hole and Mill brooks, as portrayed in plate 42, figure 6. Above or to the west of the calico conglomerate are dark micaceous quartzites, with iron ore nodules and black argillites dipping 45 degrees northwest. The conglomerate by a school-house at the Ammonoosuc crossing is close at hand; and not very far to the south, but not on the section line, is a white silicious rock carrying many minute curvatures suggestive of a possible different interpretation of the dip. West from the schoolhouse are green quartzites, chlorite phyllites,* and hornblendic layers. The coarse conglomerate near the mouth of Mill brook is interstratified with thin layers of hard green schists, and there is a notable development of this green rock before reaching the black and drab argillites.

The next traverse line is indicated in plate 42, figure 8, a general section from the Bronson limestone quarry in the east part of Lisbon, through the village to Parker hill, and about 3 miles south of the section represented in figure 5. Only one of the bands of limestone and quartzite is visible, and its position and relations to the staurolite mica schists are quite different. A faulted block is suggested both by the vertical attitude and the highly mineralized character. The argillite is identical with that at the west end of the section shown by figure 5. The Lisbon-Swiftwater complex properly begins to the left of the argillite. For a distance of 140 rods it is a mass of quartzites, obscure sandstones, and sericite schists with a northwesterly dip of 50 degrees. There is a slate in the edge of the village past a conglomerate, formerly regarded as the west border of the Swiftwater series. The strata east of this slate have been estimated to aggregate 4,000 feet, those to the west 3,500 feet in thickness. At the crossing of the Ammonoosuc may be recognized a coarse conglomerate variously modified and alternating with hard green schists. To the west are both hard and soft chloritic bands, sericite schists, chlorite-phyllites, and impregnations of galena and chalcopyrite. Near the west border is a large vein of white quartz outcropping conspicuously for 2 miles north and south, and thus enabling us to believe in a distinct unconformity of the schists beneath the argillites.* The slate belt is the Blueberry range and has the distinction of holding auriferous quartz veins which are now being worked by a company. West of the slates is a strong characteristic development of the argillitic schists, followed by dolomitic slates and auriferous conglomerates.

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* No. 127 of the Educational Series, U. S. Geol. Survey.

A section along Mill brook, in Landaff, should start with the Coös quartzite, which has quite a low northwesterly dip—say 15 degrees. It does not crop out on the stream, but on the high land, both to the north and south. The first rock visible down the stream is much like hornfels with hornblende. Half way to the Ammonoosuc river is a very coarse conglomerate by an old sawmill, dipping 75 degrees north 60 degrees west. It shows more evidences of heat than either of the quartzose ranges. Below this are an obscure schistose conglomerate and various greenish schists. At the Ammonoosuc are sericite schists; all these exposures with northwesterly dips. There are small areas of granite on Green mountain and Pond hill.

The section along the wild Ammonoosuc is the most typical, passing through the village of Swiftwater. The dips at the east end are higher, being as much as 60 and 70 degrees northwesterly and only 40 degrees on the lower side, suggesting an anticlinal or faulted segments. The first are micaceous, friable, ferruginous quartzites, with intercalated thin glossy black micaceous bands. Next are hornblendic strata and mica schists containing crystals of chlorite. Below the village are mica schists, sericitic, feldspathic, and at length a strong development of slate, followed by a coarse conglomerate midway between the village and the Ammonoosuc. The balance of the distance across to the argillites of the Blueberry range, about 2 miles, is occupied by green schists.

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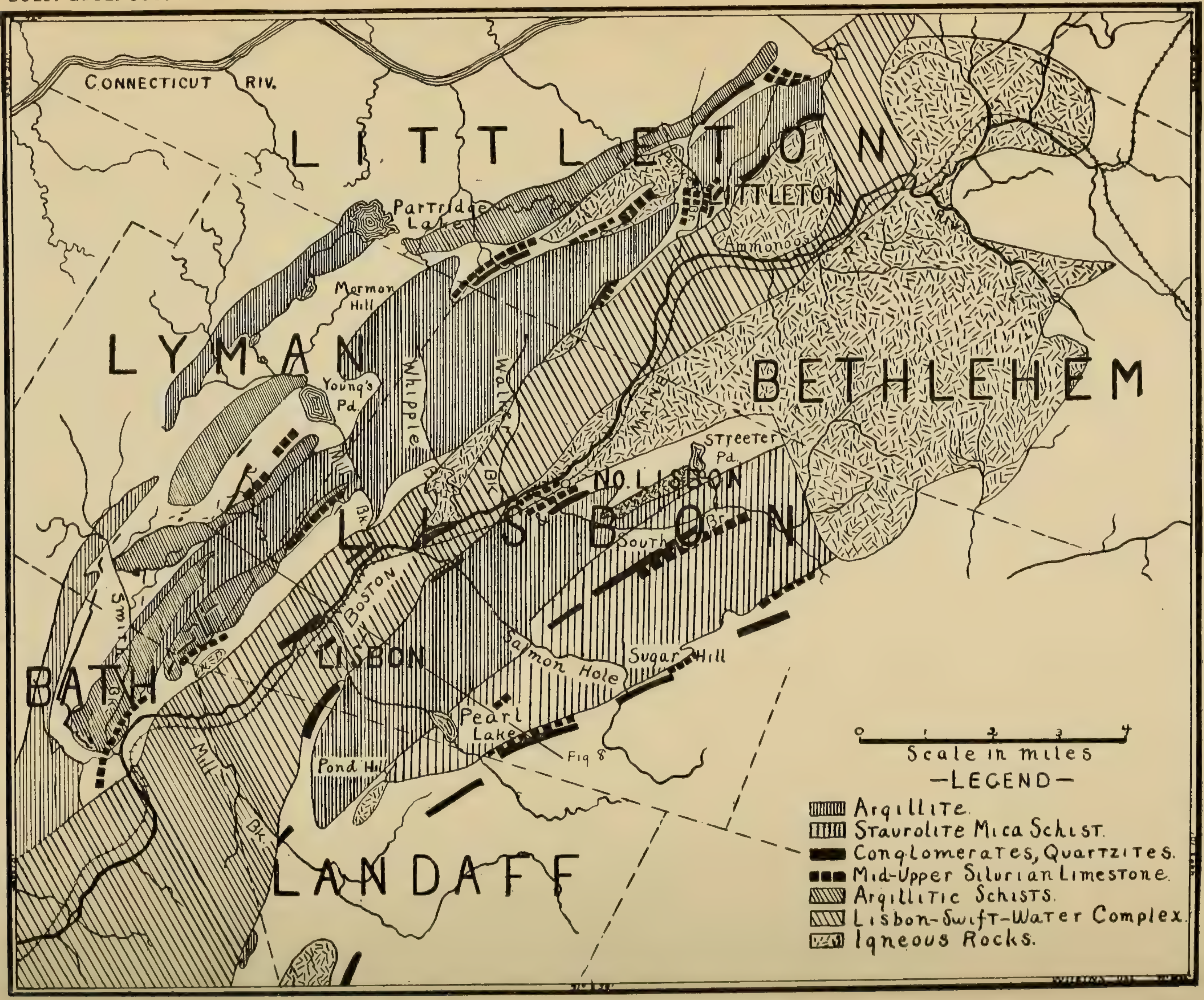
* Geology of New Hampshire, vol. 2, p. 283.


CONNECTICUT RIV.
LITTLETON
LITTLETON
Partridge Lake
Mormon Hill
LYMAN
Young's Pd.
Whipple
Walker Bk
Ammonoosuc R. Riv.
MAINE
BETHLEHEM
Streeter Pd.
NO. LISBON
South Br.
LISBON
Bk
Boston
LISBON
Salmon Hole
Sugar Hill
Pearl Lake
Fig 8
Pond Hill
Smith Bk
BATH
Mill Bk.
LANDAFF
0 1 2 3 4
Scale in miles
-LEGEND-
Argillite.
Staurolite Mica Schist.
Conglomerates, Quartzites.
Mid-Upper Silurian Limestone.
Argillitic Schists.
Lisbon-Swift-Water Complex.
Igneous Rocks.

AMMONOOSUC DISTRICT, NEW HAMPSHIRE

Description of the Map

Plate 43 is drawn to represent the regions specially described in this paper. Owing to the small scale, many of the names mentioned, the roads, and other details are not given. The order of the formations given in the legend, with the exception of the igneous rocks, is from below upward. The Lisbon-Swiftwater complex extends centrally through the area, occupying the valley of the Ammonoosuc river. In earlier maps the area in the eastern part of Littleton and a narrow strip adjacent to the granite through the township was referred to the staurolite mica schist group, of which there still seem to be a few relics, and much more has apparently been absorbed by the Bethlehem granite (page 465). The blank space in Lyman and Littleton is mostly occupied by the Lisbon rocks, and the west line of Lyman coincides with the Gardner range, averaging 2,000 feet of altitude. In the north part of Bethlehem the vacant space eating into the granite represents till. Farther south the granite itself might have been represented. The blank space to the southeast of the schists in Lisbon and Landaff is chiefly gneiss. There is also a large vacant space indicating till near Streeter pond. The scale proves inadequate to show satisfactorily the distribution of the auriferous conglomerates in Bath and Lyman; nor is the coarse conglomerate which merges into the argillitic schists to the north on Youngs pond and west of Mormon hill represented. Only one section, the most general one (figure 8, plate 42), is indicated. To have inserted the others would have obscured important details.

Conclusions

This paper may be regarded as a report of progress. The relations of the several formations are better understood than ever before, but much remains to be elucidated. It is desirable to place on record what seems to be established, to serve as a guide for later studies.

1. It is clearly established that there is a horizon of middle Upper Silurian age in the limestones of the Blueberry Mountain area.
2. In a direct upward stratigraphical succession above the limestone there are a sandstone, an argillite, coarse conglomerate, dark and drab slates. There are no fossils to decide whether any of these strata are newer than Upper Silurian, but the varied succession and the considerable thickness suggest the presence of some Devonian.
3. There is equal uncertainty as to the exact place of the supposed inferior schistose complex and the argillitic schists. At present the general term of Lower Silurian (Ordovician) may be applicable.
4. A long list of what were formerly called metamorphic schists may now be classed as eruptive igneous rocks, such as the porphyritic gran-

ite, Bethlehem granite, Lake gneiss, diorites, and protogenes, to say nothing of what has always been recognized as granite and diabase. The periods of their extrusion were evidently middle or late Paleozoic.

5. It is a fine field for the study of the metamorphism of sediments and the foliation of eruptives. There are illustrations of contact phenomena, the formation of hornfels and argillitic schists, a secondary enlargement of minerals, the modification of the forms of pebbles, the development of large garnets and staurolite, and the obliteration of the planes of stratification.

6. The general results of our studies tend to restrict the areas of the more ancient rocks, and to increase those representing the Paleozoic groups in the adjoining regions of northern New England.

DESCRIPTION OF DALMANITES LUNATUS; BY AVERY E. LAMBERT

The only fossil bearing locality that has, as yet, been reported in the state of New Hampshire is in the town of Littleton, about 2 miles to the west and north of the village.

The fossiliferous character of this area was discovered by Professor C. H. Hitchcock in 1870, while, as state geologist, he was engaged in studying the region.

The fossils, mainly coralline in character, were sent to Mr Billings, a Canadian geologist, for identification. Mr Billings believed, from the evidence which they presented, that the general term "Helderberg" could be applied to indicate the geologic horizon of this area, but later observations seem to justify the conclusion reached by Walcott that it belongs to the Niagara.

The first mention of trilobites occurring in this region is to be found in a report by T. Nelson Dale.* The material found by Mr Dale was examined by C. D. Walcott, who identified the trilobite with *Dalmanites limulurus.*†

The locality in which the trilobite occurs is on the northern slope of a range of hills known as the Blueberry mountains. This particular section of the range is owned by Mr Frank Fitch, its local designation being "Fitch hill." The fossil bearing rocks are distant from the road some 400 or 500 feet.

In ascending the hill from the road which passes in front of Mr Fitch's residence one crosses first a stratum of igneous rock. Superimposed on it is a layer of limestone, ranging from 30 to 40 feet in thickness, in which numerous coralline fragments abound. Lying on this is the calciferous slate, in which the trilobites occur. This layer is from 6 to 10 feet thick and gradually merges into the underlying limestone.

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*Proc. Canadian Institute, Toronto, vol. xxii, no. 146, p. 69.

†Am. Jour. Sci., series iii, vol. 35, 1888, pp. 79-80.

Above the slate, in order, is a non-fossiliferous limestone, a layer of coarse sandstone, and another, but non-fossil-bearing (?), slate.

All of the rocks of this area have been disturbed by the uplifting and tilting of the strata. This has affected the condition in which the fossils are found, many of them being badly distorted.

In the spring of 1903 I spent considerable time in this locality, collecting material for the museum at Dartmouth college. In this material there were several excellent pygidia of the trilobite and two cephalic shields, one of which was practically free from distortion. The present report is based on my study of the material which I obtained at that time.

There are good reasons why the trilobite from the Littleton area should not be considered identical with *D. limulurus*, as determined by Walcott. In the first place, the greater breadth of the cephalic shield in relation to its length gives it a very marked crescentic, or lunate, appearance. The length of the head from the cervical ring to the outer edge of the marginal limb, in what appears to be the most normal specimen, is hardly one-third of the total width. Mr Schuchert has also called attention to the absence of head denticulations.

In fact, in both form and general characteristics, the head of this trilobite resembles very closely that of *D. pleuropteryx* as described and figured by Hall.*

So far as I am able to discover, no determinable fragments of the thorax have been found. However, many fairly preserved pygidia have been collected. The pygidium is remarkable for its great breadth anteriorly, in which character it differs considerably from *D. limulurus*, and may, on the other hand, be favorably compared to the English *D. caudatus*.† This likeness also extends to the character of the pygidial spine, which is short and acutely triangular in both *D. caudatus* and in the Littleton species. In general appearance these pygidia bear the closest resemblance to the pygidium of a specimen of *D. pleuropteryx*, named by Green from the Lower Helderberg of Schoharie, New York, the difference being not in form, but in the fewer segments in the Littleton species, in both the middle and lateral lobes.

The differences between this form and *D. limulurus* are sufficient to warrant its being regarded as a new species. In fact, in the general character of both cephalic shield and pygidium, it approaches much nearer to *D. pleuropteryx* than to the Niagaran form, and I venture to suggest that it be known as *Dalmanites lunatus* in view of the strongly crescentic, or lunate, character of the head.

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*Nat. Hist. of New York, pt. vi, vol. 3.

†Green, in his monograph on the Trilobites of North America (1832), calls attention to the similarity between *pleuropteryx* and *caudatus*.

The following is a description of this species:

Dalmanites lunatus (Lambert).

Cephalon strongly lunate; length one-third of width.

Glabella consists of a large transversely oval frontal lobe, the longitudinal dimension being one-half of the transverse. This lobe is separated from the first of the three following lobes by a furrow which runs backward obliquely toward the median line. This furrow is broadest in its outer part. The length of the remaining lobes equals that of the frontal lobe. They are separated by narrow transverse furrows.

Facial furrow bounding the glabella laterally, deep and conspicuous, communicating more or less freely with the longitudinal furrows of the glabella.

Neck furrow deep and conspicuous, passing outward from the posterior termination of the facial furrow, and ending near the base of the genal spine.

Facial suture passes from before the frontal lobe of the glabella back to the posterior margin of the eye, then outward, meeting the lateral margin of the head at a point somewhat above the level of the middle of the eye.

Eyes compound, large and conspicuous, considerably elevated.

Pygidium triangular, broad, convex anteriorly, the middle lobe consisting of from thirteen to fifteen annulations, wide anteriorly, decreasing to one-half its width posteriorly; lateral lobes eight strongly reflexed segments which pass laterally into a broad marginal limb. The segments are marked by conspicuous furrows which are near and parallel with the lower margin. The marginal limb is produced posteriorly into a short, acutely triangular, pygidial spine.

Explanation of Plate 44

Figure 1.—*Dalmanites lunatus.* Littleton, N. H.

Cephalic shield. The specimen is considerably distorted by the lateral compression of the rock. Specimen in the museum of Dartmouth College.

Figure 2.—*Dalmanites lunatus.*

Cephalic shield. Showing the strong, crescentic curve of the frontal portion of a normal cephalon. Specimen in the possession of the writer.

Figure 3.—*Dalmanites lunatus.*

Pygidium. Specimen number D. 60. C. C. National Museum.

Figure 4.—*Dalmanites caudatus.* Dudley, England.

The Littleton species approaches somewhat near to this species in the anterior breadth of the pygidium and the acutely triangular character of the pygidial spine. Specimen number 18,475. National Museum.

Figure 5.—*Dalmanites lunatus.*

Hypostoma. Specimen number D. 60. Q. Q. National Museum.

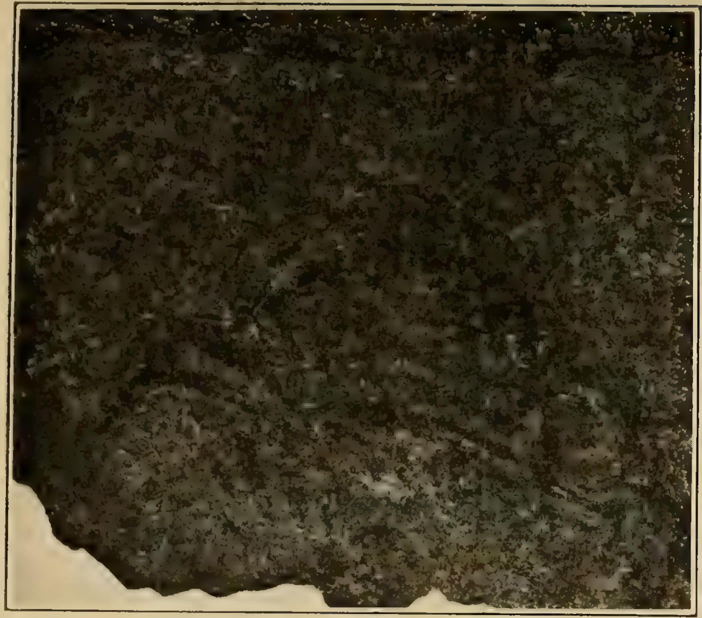


Figure 1

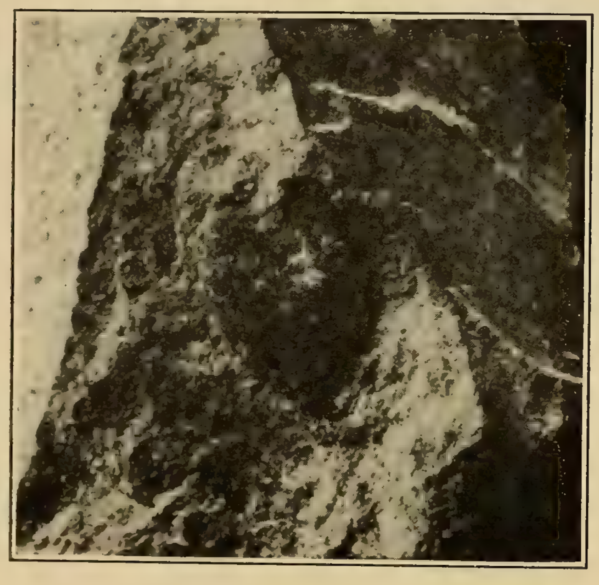
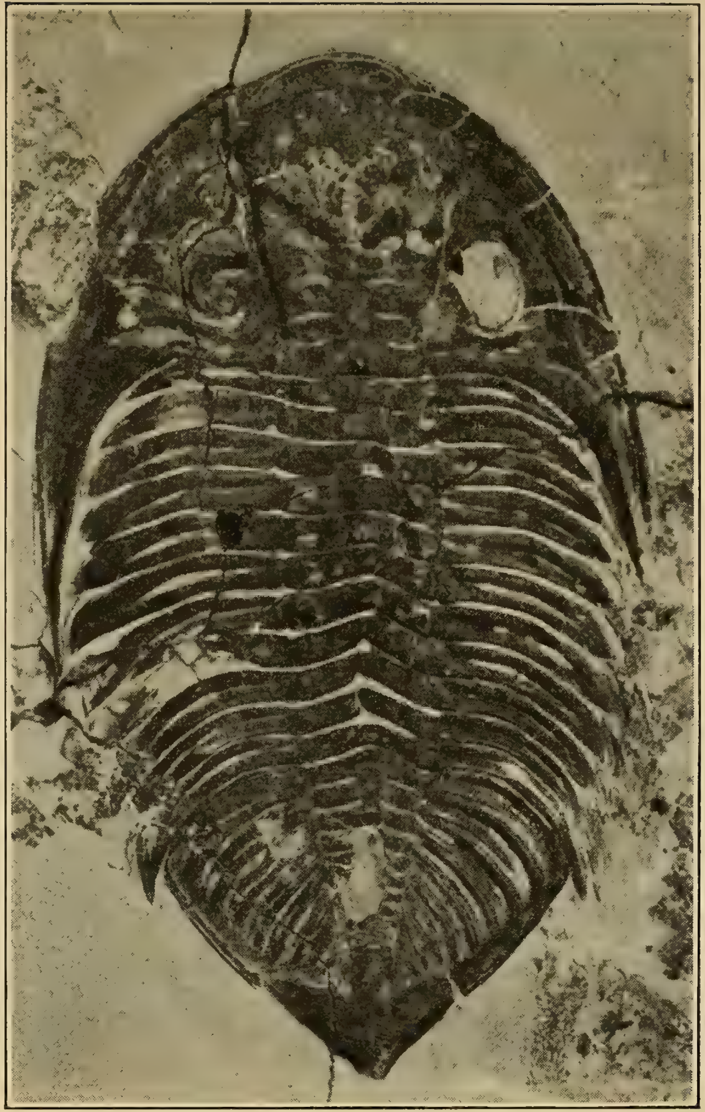


Figure 5



Figuer 4

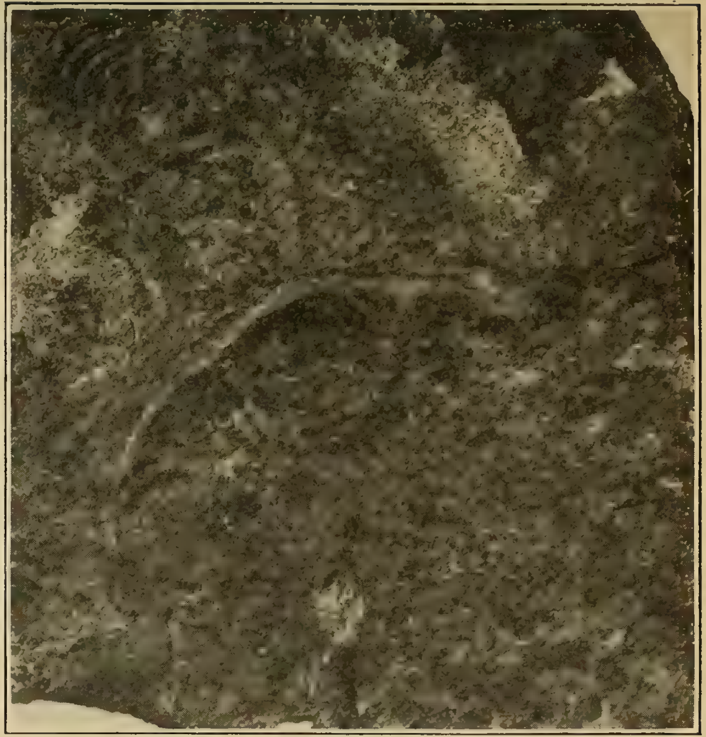


Figure 2

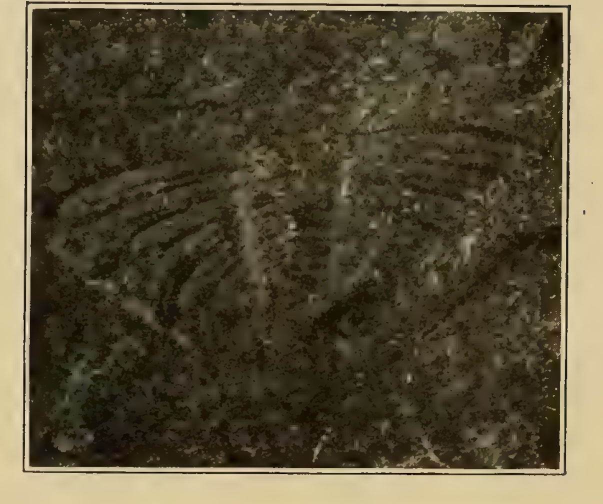
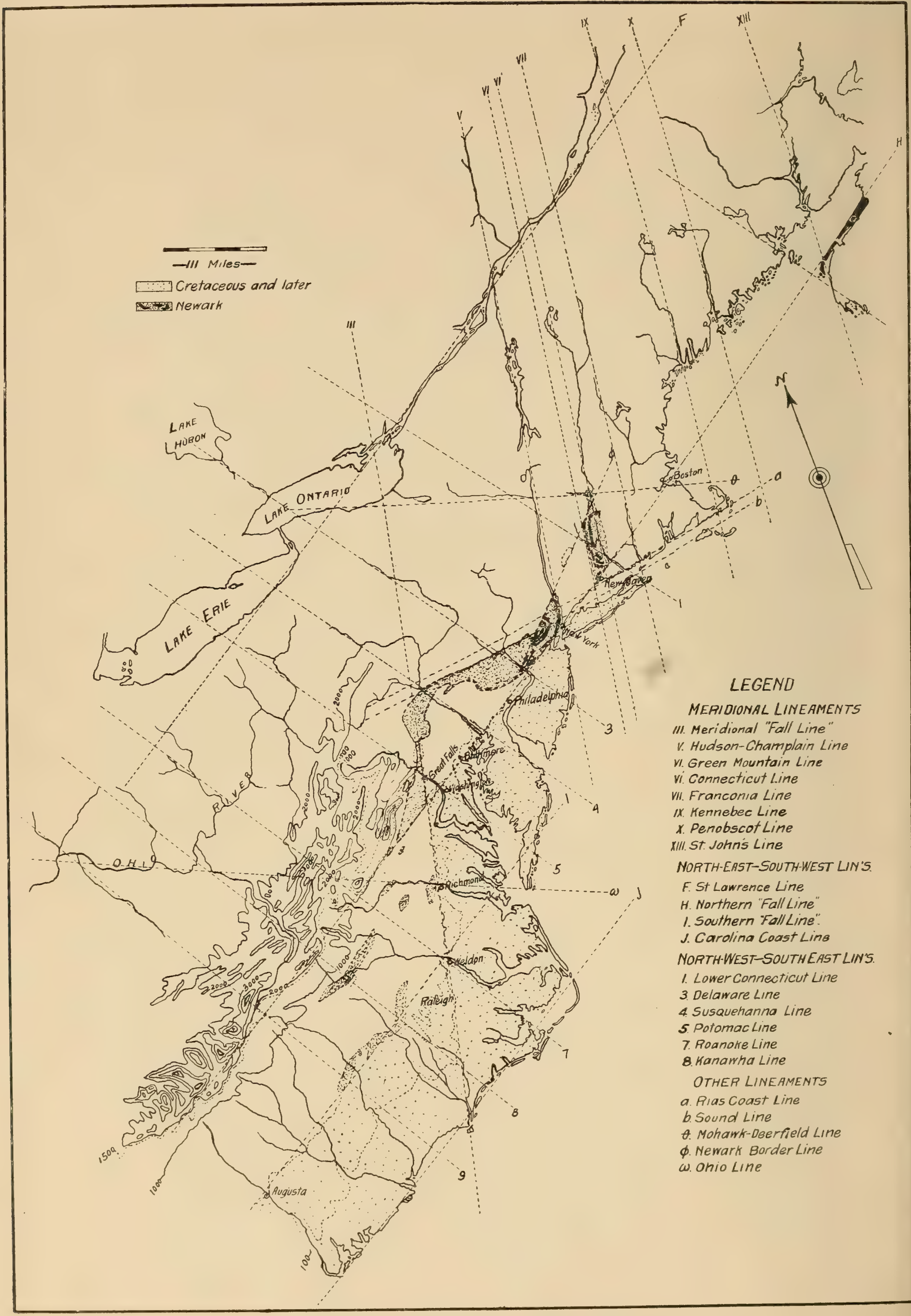


Figure 3

DALMANITES LUNATUS


III Miles
Cretaceous and later
Newark
LEGEND
MERIDIONAL LINEAMENTS
III. Meridional "Fall Line"
V. Hudson-Champlain Line
VI. Green Mountain Line
VI. Connecticut Line
VII. Franconia Line
IX. Kennebec Line
X. Penobscot Line
XIII. St. John's Line
NORTH-EAST-SOUTH-WEST LIN'S.
F. St Lawrence Line
H. Northern "Fall Line"
I. Southern "Fall Line".
J. Carolina Coast Line
NORTH-WEST-SOUTH EAST LIN'S.
1. Lower Connecticut Line
3. Delaware Line
4. Susquehanna Line
5. Potomac Line
7. Roanoke Line
8. Kanawha Line
OTHER LINEAMENTS
a. Rias Coast Line
b. Sound Line
θ. Mohawk-Deerfield Line
φ. Newark Border Line
ω. Ohio Line
Lake Huron
Lake Ontario
Lake Erie
Ohio River
Boston
New Haven
New York
Philadelphia
Baltimore
Great Falls
Washington
Richmond
Weldon
Raleigh
Augusta
N

LINEAMENT MAP OF ATLANTIC BORDER REGION

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LINEAMENTS OF THE ATLANTIC BORDER REGION

BY WILLIAM HERBERT HOBBS

(Read before the Society December 31, 1903)

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INTRODUCTION

HISTORICAL

Since the time of Élie de Beaumont and the promulgation of his somewhat fantastic pentagonal theory of the arrangement of mountain chains, the attention of geologists has been largely withdrawn from the orientation of earth features and focused on the areal distribution of geologic formations and the construction of geologic sections. It must be admitted on all sides that to this transference of effort has been due the great advance which geology has made in the period which has since elapsed. The question may now be asked, however, whether the accumulation of geologic data and the replacement of the crude maps of the earlier period by the accurate modern topographic map do not warrant a return, if not to the methods of de Beaumont, at least to a new and entirely different study of the orientation of surface features. May not too much attention be now directed to inference regarding the section, which is not often available for inspection, and too little to the ground plan of features which are everywhere open to study. The trend which has been given to geological thought in Europe, in particular by the Baron von Richtofen in Germany, by Commandant Barré and others in France, and throughout the continent of Europe by the distinguished Viennese geologist, Professor Suess, tend greatly to strengthen this conviction. The prominence which the theory of Green, regarding the genesis of the broader features of the earth, has of late acquired will further emphasize the importance of the directional element in topographic development.

The investigation discussed in this paper is an inquiry into the orientation of the dominating earth lineaments of the Atlantic Border region, with a view to determine whether they betray any law of systematic arrangement. The inquiry was suggested by the study of the southwestern New England area, and the evidence discovered there of a complex fault mosaic, the limits of which can only be assumed to be far beyond the boundaries of the province studied. Such an investigation has not hitherto been made within the region, and the scope of the inquiry presents novel features.

CHARACTERISTICS OF JOINTS AND FAULTS

The data collected by geologists respecting joints and faults have until recent years not been of a sufficiently definite character to allow of scientific correlation throughout large areas, or, in fact, even in very limited areas. Under the best present theory of the formation of block faults, their isolated occurrence is as little to be expected as would be the presence of an isolated anticline upon the present theory of folding, and it is believed, as a result of field observation, that individual faults unrelated to other planes of dislocation seldom occur. In all districts where they have been studied carefully a tendency of faults to appear like joints within essentially parallel series has been remarked. Likewise there has been observed a more or less marked tendency of the minor faults to be spaced within such a series in approximation to uniformity, and this property, so characteristic of the joints with which they are genetically connected, is one demanded by our theory of their origin through regional compression, and one which is duplicated in the faults produced artificially by the compression of an elastic body such as glass. Additional properties of joint structures which may be inferred to be also common to faults are that in regions which since their formation have been little disturbed, the joint planes stand near the vertical, and in their network two dominating series are generally found to be approximately normal to each other.

CONCLUSIONS FROM STUDY OF SOUTHWESTERN NEW ENGLAND

What is believed to be an important result of the study of the southwestern New England area is that lines of dislocation, while maintaining often with great fidelity a definite direction, do so in part along a plane whose course is the direction of the dislocation as a whole, but more largely along other planes which may make considerable angles with it, the course being here a series of zigzags. In these zigzags there may be recognized several definite recurrent directions, as well as several differing orders of magnitude, the lowest order having the joint planes for its elements (see figure 1).

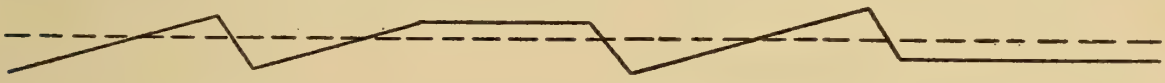

Figure 1.—*Diagram to Illustrate the Composite Nature of Lines of Dislocation.*

TYPES OF EARTH LINEAMENTS

The more important lineaments* of the earth physiognomy may be described as (1) crests of ridges or the boundaries of elevated areas, (2) the drainage lines, (3) coast lines, and (4) boundary lines of geologic formations, of petrographic rock types, or of lines of outcrops. Under the first head of particular significance are the lines of escarpment, the borders of upland areas, and the lines connecting cascades or rapids—*fall lines.* In so far as surface configuration has been brought about by the influence of fold structures within the underlying rocks, the genetical relationship will be veiled under the complex curves characteristic of such structures, except where the latter are of exceptional simplicity. Any orientation of lineaments due to joints or faults, on the other hand, in so far as this influence is now apparent, will by contrast be indicated in a more or less marked tendency of lineaments to adhere to a fixed direction, and this direction should recur in the orientation of other lineaments within the province. If a system of joints or faults is extended over a broad area, approximate equivalence in the spacing of lineaments may be looked for as a possible additional indication of this origin. In so far as such structures stand near the vertical, as is the case in the post-Newark deformation of the Atlantic border region, the course of such structures should be but very little affected by the irregularities of the surface.

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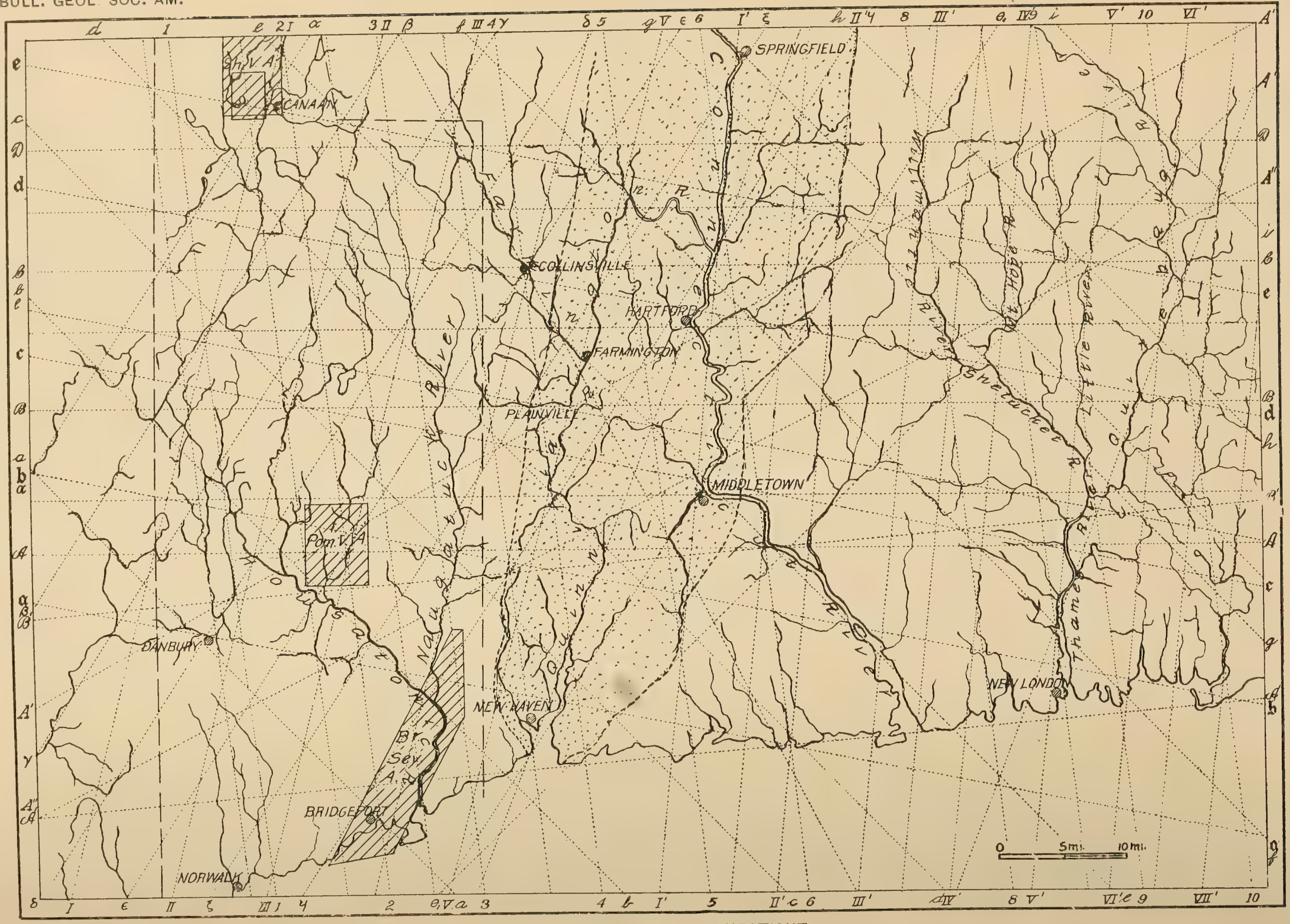
*It will be noted that the lineaments to which we have referred are not the equivalent of the "tektonische Linien" of German writers. The latter are in most, if not in all, cases regarded as lines of displacement. While believing that the greater number of rectilinear features have their origin either in planes of jointing or in faulting, there appears to be no advantage, but serious disadvantage, in giving this implication to the term. The term as here used is nothing more than a generally rectilinear earth feature.

From the existence of several types of lineament, it is to be expected that one which is manifested for a greater or less distance upon the earth's surface as a distinct type—say a scarp—may be continued as another type—let us say as a drainage line—and this again may be extended by a third—it may be as a "fall line" which intersects lines of drainage, and this again by a geologic boundary, etcetera. This composite nature of extended earth lineaments tends to conceal their presence, and careful study will be necessary for their discovery.

PROJECTION OF LINEAMENTS ON MAPS

The observation made in smaller areas that the course of a line of dislocation is not straight, but made up of a great number of straight elements composing a series of zigzags, is indication that the lineaments, which may appear rectilinear on the maps, may be so only in proportion as the scale of the map is small. Such lineaments, if traceable to dislocation of the crust for the control of their direction, must be conceived to outline in the majority of instances a complex but comparatively narrow zone of displacements, in which other directions than that given by the general trend are included. The principal dislocation, while making excursions in zigzags upon either side of its axis, does not, however, it would seem, deviate very far from this average course. Such lines, if in reality the projection of plane surfaces within the crust of the earth, will, upon maps constructed with a polyconic base, appear as curves. This necessary correction in their delineation, like the influence of erosion in everywhere molding curving outlines, has often effectively ob-


SPRINGFIELD
CANAAN
COLLINSVILLE
HARTFORD
FARMINGTON
PLAINVILLE
MIDDLETOWN
DANBURY
NEW HAVEN
BRIDGEPORT
NORWALK
NEW LONDON
Connecticut R.
Farmington R.
Naugatuck River
Housatonic
Quinnipiac
Willimantic River
Mt Hope R.
Shetucket R.
Little River
Quinebaug River
Thames River
Sh. V. A.
Pom. V. A.
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0 5mi. 10mi.

DRAINAGE SYSTEM OF CONNECTICUT

Reduced from U. S. Geological Survey map on scale of 2 miles to 1 inch scured the architectural lineaments in the landscape. If such architectural elements are present, they are for this reason little likely to force themselves upon our attention, and the key to their system will have to be sought out.

DRAINAGE SYSTEM OF CONNECTICUT

The evidence that a mosaic of joint and fault blocks has largely affected the drainage system of the state of Connecticut has been elsewhere presented.* It was found worthy of note, not only that the master streams adhere for long distances to rectilinear courses, and that after making considerable excursions to one side or the other they frequently return to these courses, but it was further determined that the drainage network discloses a number of parallel series, within which approximation to equivalence of spacing is apparent (see plate 46).

SCOPE OF INVESTIGATION

The discovery that essentially one system of control is indicated within this large area has added confirmation to the views of Davis, Russell, and the writer that the deformation by block faulting of the Newark rocks of the Atlantic border has been regional, rather than local, in its origin. It was this consideration which suggested the wider application of the same method of examination. The investigation has, however, been carried out not with a view to find certain directions among lineaments, but to fix the direction, if notably rectilinear, of all dominant lineaments, and further to see whether they reveal indications of arrangement within parallel series which approach to uniformity of spacing.

Having due regard to the danger of being misled by coincidence, the results of the study of the Atlantic border region are sufficiently remarkable to suggest the inquiry why these relationships have not before been made out. This must be explained by the localization of individual fields of study, by the so recent publication of accurate topographic maps, by the obscuring of topographic forms, due to the overprinting of culture on maps (in which the black lines of railroads and highways are forced upon the attention), by the composite nature of lineaments, by the curvature of lineaments when projected on maps, but more than all by the fact that definite orientation of lineaments has not generally been included in the field of inquiry of geology.

CONSTRUCTION OF MAP

For an inquiry into the orientation of earth lineaments the most accurate maps which are engraved on a practicable scale have been sought. The most satisfactory for the locality here under consideration is the official map of the United States Geological Survey, which is engraved on a scale of 1 : 7,033,000, or 111 miles to the inch. To form the base of plate 45 the main hydrographic lines only of this map have been traced, the culture being omitted. The official map itself and the official map on the same scale printed in solid brown tones to indicate the zones of different elevation should, however, be consulted and compared with plate 45 for the additional evidence which they furnish. The last-mentioned map brings out with especial clearness the plateau areas of the region, owing to the fact that areas less than 100 feet, between 100 feet and 1,000 feet, between 1,000 feet and 2,000 feet, and above 2,000 feet are represented by shades of increasing depth of tone. Of especial value also in the same connection is the plate printed by Powell to accompany his paper on physiographic regions of the United States,* since the borders of physiographic provinces correspond to important lineaments.

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* The river system of Connecticut. Jour. of Geology, vol. ix, 1901, pp. 469-484, plate i. See also Connecticut rivers. Science (new series), vol. xiv, 1901, pp. 1011-1012.

Lineaments have been extended on the map on the assumption that their course is the trace of a vertical plane through the crust of the earth—in other words, a great circle. For the longest indicated lineament (the line H) the direction was assumed from the position of the fall line at the two points, Baltimore and New York, and other points on the great circle determined by location first of the vertex, then of other points by the formulas used by navigators in great-circle sailing. For the meridional series, with the exception of the long Hudson-Champlain line, which is a great circle, the lines of the series are loxodromes. For the direction given these lines vary but little from great circles. This was found by trial to be true also for the northwest-southeast series on the map, owing to the fact that the medial line of the polyconic projection is far to the west.

THE DOMINANT LINEAMENTS

THE MERIDIONAL SERIES

Connecticut line.—Before searching the map at random for the indication of earth lineaments it will be well to note whether prominent lines determined for the smaller areas studied or indicated by the hydrography of Massachusetts and Connecticut appear to extend beyond the limits of these areas. Within the Connecticut area the direction which is perhaps most strongly brought out in the drainage is that which trends north 5 ± degrees east. This direction of earth lineaments was first discovered through the study of the drainage of the eastern half of the state (east of the Connecticut river).* This direction of drainage is peculiar to the section of the river itself above Middletown (see plate 46.) By examination of plate 45 it will be seen that this line (VI) is continued northward 50 miles or more beyond the borders of Connecticut. Not only is it for nearly 100 miles an important line of drainage, but examination of a geologic map † will show that it is for long distances on the border of Vermont and New Hampshire the formation contact of the Archean with the Cambrian in some instances and with the Silurian in others.

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* The physiography of the United States, 1896, pp. 65-97.

Hudson-Champlain line.—If now we examine the map of plate 45, we note that this bearing is the dominant direction assumed by the larger New England rivers. The Jersey shore also, with the gorge of the Hudson, the rift of lake Champlain, and the long rectilinear courses of the Richelieu, Saint Maurice, and Croche rivers, together make an almost uninterrupted hydrographic line (V) more than 600 miles in length, which extends from Barnegat, New Jersey, more than 100 miles beyond the Saint Lawrence river. If we examine the larger scale maps of the same region, we observe that this course is maintained through a series of zigzags, but yet by zigzags which never pass far to either side of the main direction. Such a line, whose course is maintained with such amazing fidelity, seems to be in every way analogous to the course of the cliffs of the Palisades from Bayonne to Edgewater, a course maintained through zigzags in which several other fault series play a rôle, as they do, in fact, in nearly every fault cliff which we examine. This remarkable line has in the Lake Champlain section been recognized as a line of dislocation, and is designated by the Canadian Geological Survey as a part of the great Saint Lawrence-Champlain fault.‡ In its southern section, near the city of New York, the writer has shown that it represents a line of dislocation along which the Newark formations of New Jersey are set down into the crystalline rocks lying to the east of the Hudson.§ Between the Hudson-Champlain line (V) and the Connecticut line we find a range of mountains (the Green mountains and Berkshire hills) which maintains the same direction, though west of the Hudson the axis of the Appalachian chains is inclined to this direction by 60 degrees or more. Not only do the Hudson-Champlain and the Connecticut lines and the Green Mountain range itself maintain a common direction (north 5 degrees east along the Hudson river), but the east base of the Green mountains also can be followed on the government map as a distinct line having this direction from lake Memphremagog on the north to the latitude of Springfield, Massachusetts, on the south, beyond which point southward the line is continued as the approximate western border of the Newark area of the Connecticut valley with the crystalline uplands (VI).

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* The river system of Connecticut. Jour. of Geology, vol. ix, 1901, pp. 469–584, two plates.

† Map of the United States, exhibiting the present status of knowledge relating to the areal distribution of geologic groups. (Preliminary compilation.) Compiled by W J McGee, Washington, 1884. Plate II of the Fifth Annual Report U. S. Geol. Survey.

‡ Cushing has used the name "Champlain fault" for a parallel dislocation in this vicinity. Fifteenth Annual Report State Geologist of New York, p. 572.

§ Bull. Geol. Soc. Am., vol. 13, 1902, p. 143.

Franconia line.—To the east of the Connecticut we find a line formed by the Thames and Little rivers. This line is continued across the White Mountain mass of New Hampshire as the famous Franconia notch, which, with its continuation, the Pemigewasset river, extends along this direction from the Profile house on the north to West Thornton (about 20 miles) on the south, as an almost rectilinear furrow through the mountains (VII). Again, north of the notch this line is for 30 miles or more the course of the upper reach of the Connecticut river.

Kennebec, Penobscot, and Saint Johns lines.—Eastward still the same direction is brought out in the courses of the Kennebec (IX) and the Penobscot (X) in Maine. Without attempting to follow in detail the course of these lines, we may note the one (XIII) which, skirting the western shoreline of Nova Scotia, passes through a cleft (Petit passage) in the trap ridge of the northwest margin and is followed to the north in the zigzagging course of Saint Johns river.* Along the course of Saint Johns river this line is one along which formations abruptly end.†

Within the region of New England and the provinces the lines of the series are spaced with an approach to uniformity. The Hudson-Champlain line (V), the western Connecticut line (VI), and the Franconia line (VII) are, in the latitude of Boston, something over 40 miles apart. This is also the approximate distance separating in the same latitude the Kennebec (IX) and the Penobscot (X) lines, while the space between the Franconia and Kennebec lines is a double interval.

Meridional fall line.—West of the Hudson the line of this series which appears prominently on the map is, however, much farther separated from the Hudson-Champlain line. This line (IV), from the Great falls of the Potomac, passes southward from Richmond and Weldon as a section of the fall line described by Powell, and, as shown by him, is the boundary line of the crystalline rocks on the west, with the Cretaceous and Eocene on the east. Near the Great falls of the Potomac this line follows a dike of Newark trap and crosses the state of Pennsylvania a little west of but parallel to the course of the Susquehanna. To the south of Weldon, near which place the fall line makes its sharp bend to the west, the line is continued southward in the topography along the 100-foot contour line.

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*By the Gaspereaux, the T-like arms of the Mirimichi and the Nepisiquit, the line is carried across New Brunswick to the Saint Lawrence.

†See in "Acadian Geology" (1868), a geological map of Nova Scotia, New Brunswick, and Prince Edward Island, by J. W. Dawson.

THE NORTHEAST-SOUTHWEST SERIES

Northern fall line.—By reference to the paper on Connecticut Rivers* or to plate 45, it will be noted that a single line of definitely oriented drainage along the direction measured as about north 48° east was indicated on the map, though it was not found to be in correspondence with any of the Pomperaug Valley faults, and was apparently without indicated parallel lineaments in its vicinity. This line (H of plate 45) passes along the entrance to New Haven harbor, while northeast of New Haven for about 14 miles it follows the nearly rectilinear formation boundary of the Newark system with the crystallines. Farther northeast, as already indicated, it is in approximate correspondence with the course of the Salmon river and with a branch of the Willimantic (see plate 46). Still further extended along this direction it passes near the northern shore of Massachusetts bay, and in Canada, the basalt bluffs forming the steep southeast shore of the bay of Fundy.

To the southwest from New Haven this line (H) is in approximate correspondence with the Connecticut coastline (a "Rias" coast) and with the western section of Long Island sound. Southwest of New York city its course is along the remarkable series of sharp and straight arms of the Delaware river and the drowned Susquehanna and Potomac. It thus connects the city of New York with Trenton, Philadelphia, and Baltimore, and is, as shown by Powell,† a portion of the lineament, traceable as far south as Macon, Georgia, along which the ancient mass of the crystalline rocks to the westward is in contact with the later Cretaceous and Eocene deposits on the east. It is also a terrace line on the land, and it is represented by rapids and falls in the streams. South of the Potomac this fall line turns sharply to the southward, but the line we have been following is continued in close correspondence with the western border of the Piedmont plateau, as mapped by Powell. The steep eastern wall of the Appalachian ranges begins at the 1,500-foot contour line, and the high peaks of the range are to be found quite close to this line. The wavy course of this 1,500 foot contour is outlined on plate 46, where its general course is in correspondence with the lineament we are considering.

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* Loc. cit.

† J. W. Powell: Physiographic regions of the United States, National Geographic Monographs, vol. i, no. 3, 1895, p. 73.

Carolina coastline and southern fall line.—Parallel to the northern fall line above referred to runs for about 400 miles the gently escalloped coastline of the Carolinas (J). Almost exactly midway between it and the line H is found a parallel line of the series (I), which is hardly less marked than the first described, and for the similar reason that it is in coincidence with the southern fall line from near Raleigh, North Carolina, southwestward through Augusta to Macon, Georgia. As subsequently shown by the geological survey of Georgia, this fall line continues beyond Macon to Columbus, on the border of Georgia and Alabama.* The margin of the Eocene deposits with the crystallines (see course of dotted line in plate 46) is along this line, only less in coincidence than was the Cretaceous-crystalline border with the first described line of this series (H). Where the Eocene is covered by Quaternary deposits near Augusta the fall line has been assumed to be near the course of the covered boundary.

It is worth noting that the southern Newark areas are largely enclosed between the lines H and I, which the eastern and western belts of that system approach respectively. It may also not be without significance that the almost constant dip of the beds in the western chain of areas (Dan river, Danville, Richmond, etcetera) and the Nova Scotian area are to the westward, whereas the eastern series (Wadesboro and Deep River areas) have dips to the eastward. These dips are for the most part from 15 to 28 degrees except near the western boundary line, where they either change direction or become steeper.† To the west of the line H the irregular outline of the Newark areas corresponds to marked changes in the dip. In the Connecticut and Pomperaug Valley areas, however, the dips are uniformly southeastward or toward the larger dislocations. These dip measurements, when constant over large areas, are believed to afford valuable data regarding the tilting of the blocks, since folding is practically absent from them. The marked irregularity in dip and its higher angles, as has been said, doubtless indicate the proximity of a main line of dislocation. In this connection the statement of Russell concerning the supposed synclinal structure of the bay of Fundy is not without interest: ‡

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* Thomas L. Watson : A preliminary report upon a part of the granites and gneisses of Georgia. Geol. Survey Georgia, Bull. 9 A, 1902; plate opposite p. 88.

† "In the Dan River area, especially, the high dip of the Newark system, amounting in many instances to nearly 50 degrees within a few rods of the line of junction with the crystalline rocks, is a very strong indication of marginal faulting."

"The Danville and Dan River areas are remarkable for the high inclination of the strata composing them. In many places, throughout continuous sections over a mile in length, the beds have a persistent western dip at angles varying from 35 to over 50°." I. C. Russell : The Newark System. Bull. 85, U. S. Geol. Survey, 1892, pp. 85 and 86.

‡ Loc. cit., p. 80.

> "The general dip of the rocks along the eastern border of the bay of Fundy is northwest at an angle of about 15 degrees. On the New Brunswick shore there are several isolated areas belonging to the same system which dip southeastward at angles varying from 25 to 35 degrees. These inclinations have led to the conclusion that the Acadian area has a synclinal structure. That such is the case, however, can not be accepted as a final conclusion, for the reason that a faulting or tilting of the strata would account equally well for the observed dips. In the eastern part of the Acadian area, about the Minas basin and Cobequid bay, the strata are much disturbed and dip toward all points of the compass, and are at all angles from near horizontality up to nearly 50 degrees or more. Some faults have been recognized in this region, but a characteristic fault structure, although indicated, has not been demonstrated."

Saint Lawrence line.—Another line of this northeast series is that great lineament (F) which follows the course of the Saint Lawrence river from lake Ontario to near its mouth (a distance of over 400 miles), and is continued southwestward beyond the border of the map as the western border of the Alleghany plateaus, as mapped by Powell. Along the Saint Lawrence for a part of the way this line is the course of the great "Saint Lawrence-Champlain" fault, as mapped by the Geological Survey of Canada.

The series of lineaments which have been above described mark off in a quite accurate manner the physiographic regions of the Atlantic border. It has also been noted that, to a considerable extent, the lines correspond to formation boundaries (especially, however, I and H). Topographically they mark off also a series of plateaus increasing regularly in height, after the manner of a flight of stairs, as one passes inland from the seacoast. In this series are, beginning at the shoreline, the Atlantic plain (I–J to the south), the Piedmont plateau (H–I), and the Appalachian ranges (from H west to the Cumberland plateau). From the elevated region reached in the Appalachian ranges the country is "stepped off" by plateaus descending in the opposite direction—the Alleghany or Cumberland plateaus and the central plains of the upper Mississippi valley.

As bearing on the relation of the Saint Lawrence line and the northern fall line to the eastern shore of the Atlantic, a suggestion by Professor Suess* is interesting:

> "This series of surmises leads to the conclusion that under the north Atlantic there is on the north a broad Archean region and south of the same a curved chain folded toward the north, in which the Upper Carboniferous rests in discordance on older eroded folds.
>
> "4. It is a very remarkable fact that the east coast of North America actually corresponds to these surmises. There appear here, in fact, with the exception of

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*Sitzungsber. d. k. k. Akad. d. Wissensch. in Wien, vol. cvii, Abth. I, 1898. Translation by Emerson in Bull. Geol. Soc. Am., vol. 11, 1900, p. 102.

some possible Caledonian tracts, only two tectonic elements which show the essential characteristics of *d* and *f* [*d* the Armorican folds, *f* being the western Hebrides and a small part of the peninsula of western Scotland.—Ed.]. They are separated by Belle Isle straits and the lower course of the Saint Lawrence river. To the north lies the broad Laurentian-Archean mass—the Canadian shield—and probably extends broadly toward the pole beneath the horizontal Paleozoic sediments of the Arctic American archipelago; also extending across to Greenland. South of the same, in the rias coasts of Newfoundland, Nova Scotia, and New Brunswick, appears a region of folded rocks with discordant transgressing Upper Carboniferous, which is as plainly the western continuation of a great folded chain as in Europe the Armorican ridges are the east end of such a chain."

It is, perhaps, well here to repeat that these lineaments, represented on the map as straight lines, are found to be complex so soon as observed on maps of larger scale, where they appear, as has been said, as lines of zigzags, and hence they are to be regarded as zones which on the scale of the map may be regarded as narrow. They are represented as lines only, because on the scale of the map the breadth of the zone is nearly or quite inappreciable. When, therefore, in the descriptions of the lineaments the statement is made that this or that line is continued as such or such a lineament, it should be understood that the narrow zone is thus extended and not any particular line within that zone.

THE NORTHWEST-SOUTHEAST SERIES

Saint Croix line.—Not only do the maps disclose the existence of a series of lineaments and of crustal slices which trend parallel to the coast line of the Carolinas, but series directed nearly at right angles are hardly less in evidence. In the Connecticut area (plate 46) the direction north 34 degrees west was indicated as the more characteristic of faults along this general direction in the special area of the Pomperaug valley. With it, however, were observed dislocations of a series trending north 44 degrees west. The river system of the state as a whole shows, however, with some clearness that the latter series is in that larger province the dominant one. Examination of the rivers of the Atlantic border region, as we shall see, furnish evidence that dislocations approximating to the northwest southeast direction have controlled. Without attempting to refer to all lineaments which are there indicated, a few deserve special consideration. Beginning at the northeast, a line of the series follows the southwestern shore of Nova Scotia so as to terminate the trap walls, and at the same time the Newark basin of that province. Farther southeast upon the peninsula this line passes between masses of igneous rock in a way which may indicate offsetting. The course of this interesting lineament has been represented by figure 2.

On the mainland this course follows, as a narrow zone of parallel lines, the course of the Saint Croix river, so as to terminate abruptly or to indicate offsets in the boundaries of the members of the stratigraphic series represented along it, especially, however, in the igneous rocks, the Upper Silurian, and the Devonian.

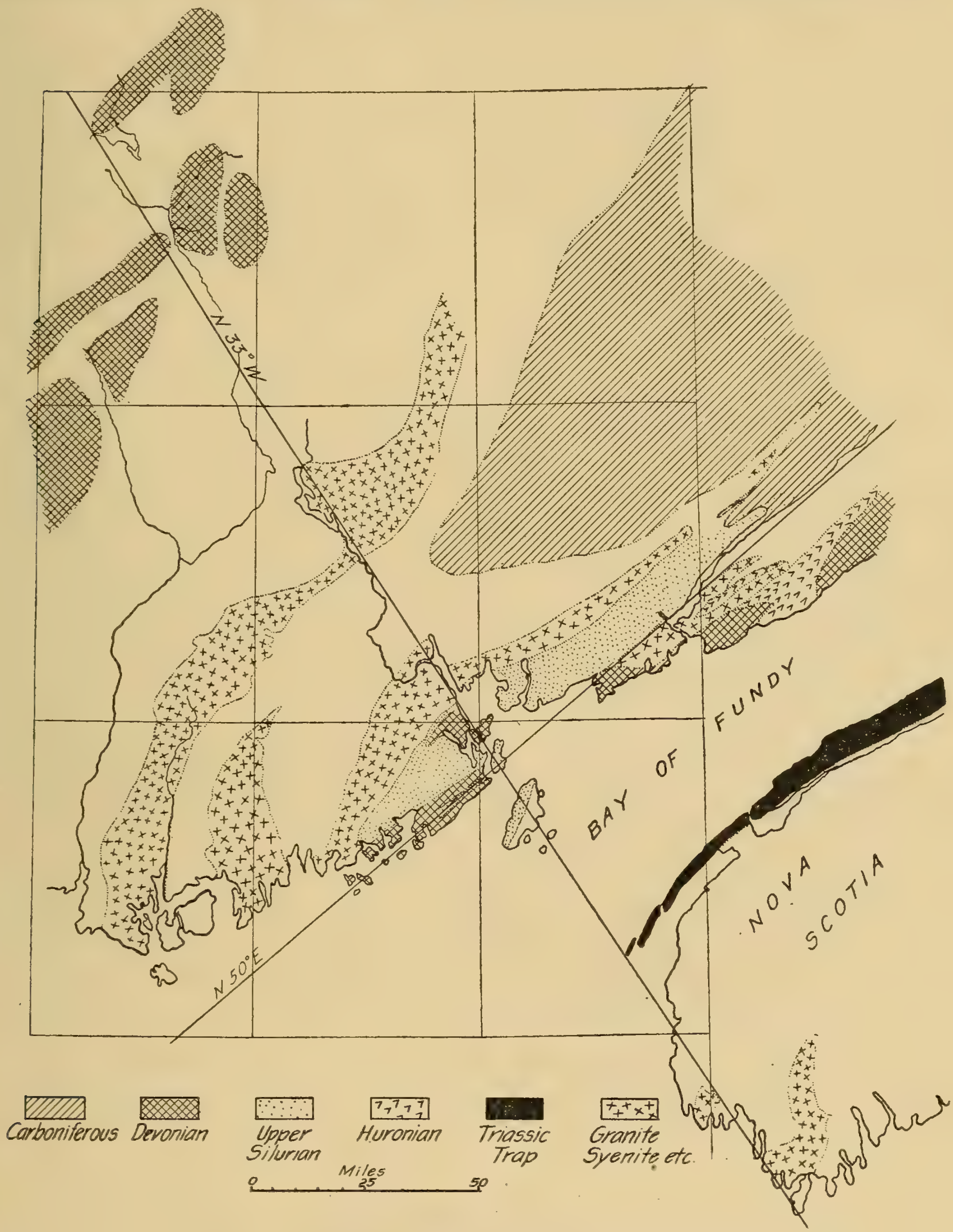
N 33° W
N 50° E
BAY OF FUNDY
NOVA SCOTIA
Carboniferous
Devonian
Upper Silurian
Huronian
Triassic Trap
Granite Syenite etc.
Miles
0
25
50

Figure 2.—*Map of the Saint Croix Line of Displacement* (*after Dawson's Map*).

Lower Connecticut line.—Of the lineaments of this series which have been represented on the drainage map of Connecticut (see plate 46) only one has been extended on plate 45. Examination of the official United States map, on which plate 45 is based, will show that throughout the Green Mountain area branch streams largely incline to follow a northwest-southeast direction. On plate 45 the course of a line of this series can be followed from Long Island sound northwestward nearly along the course of the Connecticut below Middletown, along the Farmington river, across the Adirondack region in approximate correspondence with Black river, along which the Adirondack gneiss abuts against the Trenton.*

Other lines of the series.—Southwestward from the city of New York the courses of the northwest-southeast lineaments are marked out in the Delaware, Susquehanna, Potomac, Cape Fear and Kanawha, and the Savannah rivers. The line 3 is not only the course of a lower section of the Delaware, but it corresponds approximately to the upper course of the Susquehanna for a long distance. Extended, this line would correspond approximately to the ancient outlet of lake Huron. The line next south (4) (see plate 45) follows the lower Susquehanna, as the Delaware line does the upper. Another line (5), having approximately the same direction, follows the Potomac, and, in the vicinity of the Great lakes, the Alleghany river. The line 8 is the course of the Cape Fear and Kanawha rivers. Where it crosses the Newark formations on the border of North Carolina it appears to do so through a narrow gorge (a *graben* or rift valley), which separates the Danville from the Dan River area. Concerning this gorge Russell says: †

> "The Danville area terminates abruptly at the south, and appears to have been separated from the Dan River area by a profound displacement trending northwest and southeast, or at right angles to the prevailing strike of the rocks."

The northwest-southeast trending series are of especial interest in their connection with the interruptions of continuity in the Newark system. Attention has already been called to the way in which the Danville and Dan River areas are separated by a displacement along this direction. Hardly less worthy of mention is the indicated lineament which follows the Roanoke river past the city of Weldon, North Carolina, and is extended westward as a marked drainage line. Parallel to this direction and in its neighborhood is a dislocation which Russell thus describes: ‡

> "The abrupt manner in which the strata at the northeast extremity of the Danville area abut against the crystalline rocks, when followed northwestward along the strike, is well shown near the little hamlet of Cascade. The junction of

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* See Merrill, Geological Map of New York, 1901, Saint Lawrence Sheet.

† Loc. cit., p. 86.

‡ Loc. cit., p. 86.

> the two formations is a straight line at right angles to the strike of the Newark beds. Along the line of junction the Newark strata dip northwest at angles varying from 30 to 35 degrees.
>
> "This locality has not been thoroughly studied, but from the reconnaissance made it seems as if the Newark strata had been depressed into the crystalline rocks along the junction of two faults which meet each other at nearly right angles."

The rectangular " elbow system," so well illustrated by the Susquehanna and Delaware rivers, includes an upper reach of the latter stream, which is northwest of the city of New York. Its direction continued to the southeast is in approximate correspondence with the buried channel of the Hudson, beginning 10 miles from Sandy Hook and extending with a single brief interruption some 60 miles to seaward.*

OTHER LINEAMENTS

Orientation of the three principal series.—The three series of lineaments already described are the meridional series (north 5 degrees east), a second series averaging 50 degrees east of the meridian, and a third series near 43 degrees west of the meridian, and here because of their moderate extension and position on the map projection, coinciding in direction with the lines of common azimuth. It must have been noted that there is less correspondence between the rivers outlining lineaments in this series than in the other two. The line along the Saint Johns river has the direction north ± 33 degrees west (see figure 2). The others have been drawn on the map as about north 43 degrees west, but it is noticeable that west of the Appalachians the markedly rectilinear streams which approach their direction have the direction north ± 33 degrees west. The directions north 34 degrees west and north 44 degrees west were found to characterize many faults in the Pomperaug valley, Connecticut, and the same divergence of northwesterly flowing streams is made out on plate 45. With the individual exceptions shortly to be mentioned, the lineaments comprising these three series clearly constitute the stronger tectonic lines of the region—the lines indicated by the larger rivers, the coastline, the formation boundaries, the borders of plateaux, the main mountain ranges, and the boundaries of physiographic provinces. Larger scale maps than the one used would reveal many other directions, and careful search of the map here used as a base would bring out new lineaments, both in the series mentioned and in other series. The aim has been, however, to draw attention to the dominant lineaments only.

Newark border line.—A tectonic line not strikingly revealed on the small scale topographic map is in southwestern New England and southeastern New York, rather clearly indicated by the boundaries of Newark areas and of the Kent-Cornwall core of gneiss, which lies between them. This line bears about 30 degrees east of the meridian and forms the northwestern border of the New York-Virginia area of Newark for a distance of some 30 miles, where it is recognized by Darton * as a fault boundary. It likewise forms a part of the border of the Connecticut valley Newark, and about half way between these areas it follows the gorge of the Housatonic river along the border of Stockbridge dolomite with gneiss.

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*A. Lindenkohl: Geology of the sea bottom in the approach to New York bay. U. S. Coast Survey Rept. 1884, Appendix 13, pp. 435–438.

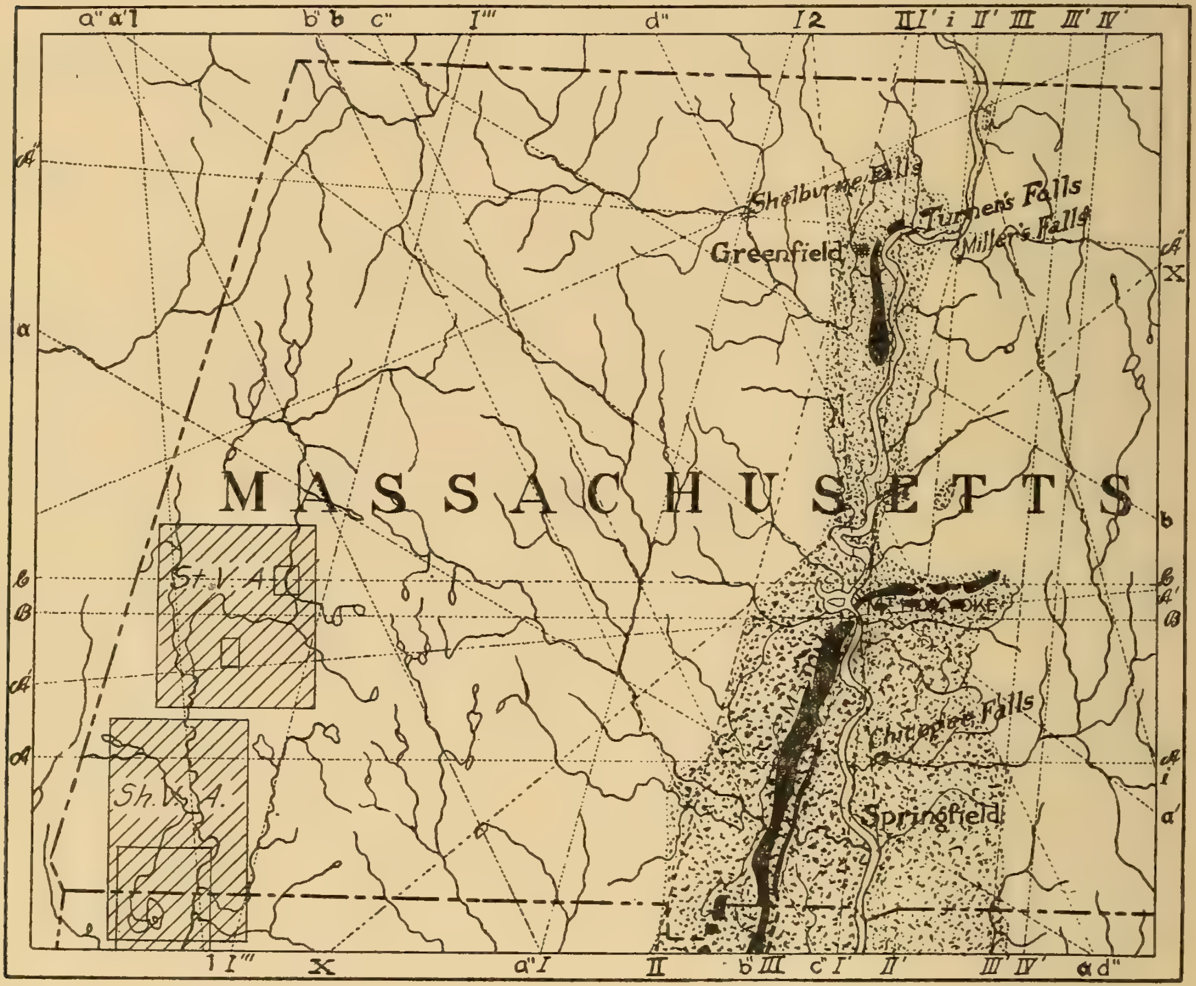


FIGURE 3.—*River Map of a Part of Western Massachusetts.*

The dominant lines of the local network are indicated, as are the boundaries of the Newark system, by the stippled area, and the basalts of that system by the black.

Rias coast and sound lines.—It has already been pointed out by Emerson that the southern shore of New England is a Rias coast, explained by the depression of a crustal block to the southward of the coast. From inspection of the map (plate 45) it will be noticed that this coast is, as regards its general trend, remarkably regular, and its direction is continued westward in New Jersey and Pennsylvania parallel to the border of the large Newark area in that vicinity. That border itself projected eastward along the same direction passes near the northern shore of Long island (see lines *a* and *b* of plate 45). The direction of these lineaments is about north 65 degrees east.

---

* New York Folio, U. S. Geol. Survey, p. 6.

Mohawk-Deerfield line.—Another dominant line, and, so far as is apparent from inspection of the map, not parallel to any similar lineament, is that which I have denominated the Mohawk-Deerfield line (Θ). This strong lineament outlines the great central valley of New York state, separating the Hudson River rocks to the north from the newer sediments upon the south. Continued westward it runs parallel to the long axis of Oneida lake, while eastward from the Hudson its general course corresponds closely to the gorge of the Deerfield river, along which the Fitchburg railroad has found a way across the uplands. In the vicinity of the Connecticut river it is a fall line, on which are located Shelburne and Turners falls, and it terminates the basalt flows of the Newark, where they turn to follow this direction for a short distance (see figure 3). The Connecticut here makes a sharp turn to the east, and is entered from the east by Millers river, whose course follows the same direction. Still farther east the line approximates the southern shore of Massachusetts bay. The bearing of this lineament is about north 75 degrees west for its whole distance, but more nearly north 85 degrees west in the section immediately adjacent to the Connecticut river.

Holyoke line.—Any geologist who has examined the map of the Newark area of the Connecticut valley must have been impressed by the fact that the much-faulted Holyoke range meets the main direction of the flow of the district almost at right angles, or in a nearly east-and-west direction. Emerson has shown that a line of volcanic plugs marking the course of a fissure line in the crust extends in a direction parallel to the range and a little south of it (see figure 3). Both to the east and to the west from this line of plugs the Connecticut receives tributaries along the direction of the fissure. Extended west, this line coincides with the great westwardly offset of the Housatonic, which has been recognized as the course of a fault by both Emerson and the writer (see figure 4). Westward in central New York this east-west lineament is parallel to but not quite coincident with a long T-like branching of the

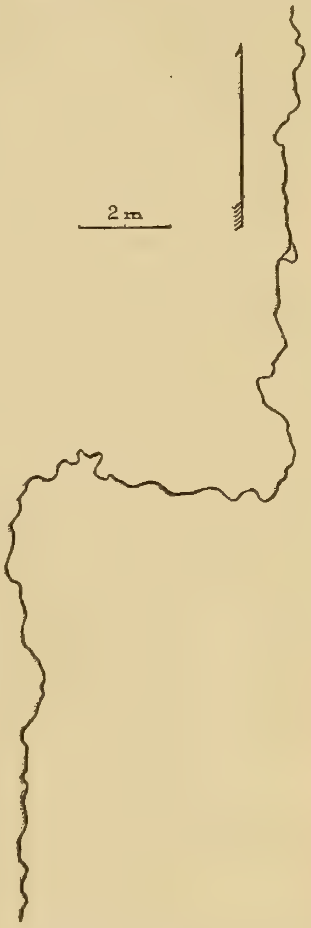


FIGURE 4.—*Course of the Housatonic River in the Vicinity of the Great Bend at Lee, Massachusetts.*

Susquehanna river. Owing to its short extent and the difficulty of representing the facts on the map, this line does not appear in plate 45.

Ohio line.—Another strongly marked lineament (ω) follows a direction somewhat farther removed from the equatorial along the courses of the Ohio river and the Roanoke river in Virginia.

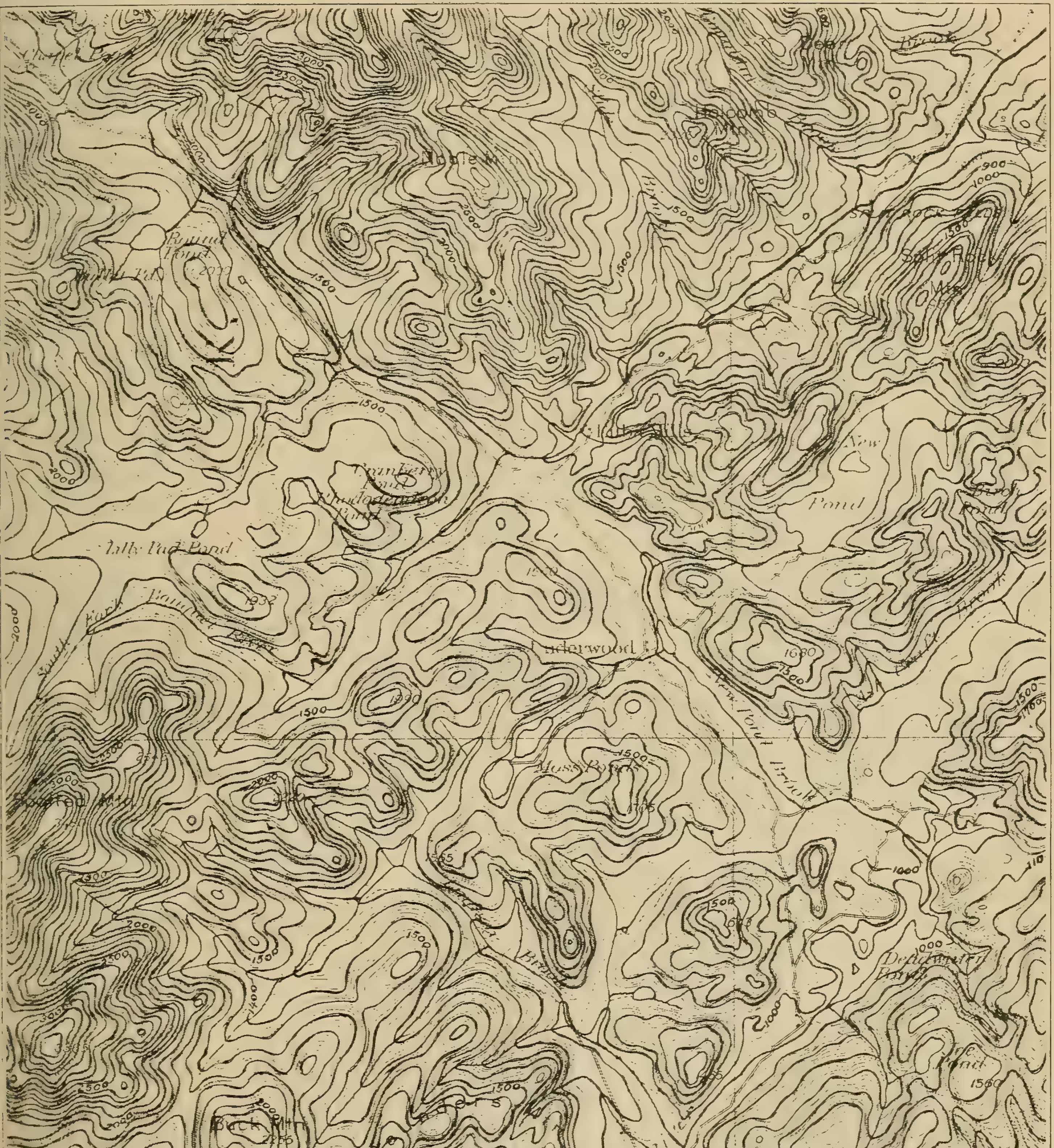
CHARACTERISTICS OF THE NETWORK OF LINEAMENTS

From what has been said it would appear that the dominant lineaments of the Atlantic coast region of North America are largely included in a nearly meridional series and in two other series which make nearly equal angles with this direction. Other lineaments which more closely approach the equatorial direction vary more from one another and are both numerically less important and less strikingly brought out. It can hardly be regarded as accidental that in all of the three series the spacing should approximate so closely to uniformity, or, when intervals of exceptional width occur, that they should constitute multiples of the normal intervals. This uniformity of spacing is indicated in the numeration adopted for the lineaments on the map. The normal interval of the meridional series is in the latitude of Boston about 40 miles; that for the northwest-southeast trending series is about 75 miles, while that for the northeast-southwest series approximates 125 miles. As already pointed out, some approach to uniformity of interval within a series should be expected if the lineaments are to be referred to disjunctive processes and if faults of similar magnitude are spaced with the same regularity as are the joints with which they are genetically connected.

Inspection of the map reveals the fact that the area to the east of the Hudson-Champlain line is noticeably different, as respects the dominance of its striking lineaments, from the area lying to the west of the same dividing line; since to the east of this boundary between physiographic provinces, the control of topography and of drainage has been exercised largely by the meridional direction. A rectangular or checkerboard structure is evident in the region of the middle Atlantic states, as a result of the dominance of the northwest-southeast and northeast-southwest elements. On a smaller scale this type of topographic development is well exemplified in the Adirondack province (see plate 47).

EVIDENCE THAT SYSTEMS OF REGIONAL JOINTS EXTEND OVER WIDE AREAS

Comparatively few geologists have put on record the directions of prevailing joints within the regions which they have studied. Until such studies have been undertaken the fragmentary records now at hand must


Underwood
Lily Pad Pond
Round Pond
Cranberry Pond
Rhododendron Pond
New Pond
New Pond Brook
Moss Pond
Holcomb Mt
Noble Mt
1500
2000
1000
NORTH HUDSON

CHECKERBOARD TOPOGRAPHY

Due to nearly rectangular block faults. From U. S. Geological Survey map of Adirondack region

be found insufficient for the satisfactory correlation throughout large areas. There are, however, some indications that they will be found to be more generally in accord than has usually been supposed.

The most comprehensive studies of the joint directions which have been made in the United States are those by Shaler and Tarr* in Massachusetts, and by Buckley† in Wisconsin. The first mentioned study is a comprehensive investigation and elaborate averaging of all joints which were observed within a small district of complex structure; the last mentioned, on the other hand, a comparison of the master joints found at numerous widely separated localities within a large area in Wisconsin. Shaler and Tarr in the Cape Ann district found that the joints are included in a large number of series and are quite uniformly spaced within each series. Measurements of the joint intervals were in many cases made. For the area as a whole, it is found that the greater number of joints trend in the directions north 20 degrees–25 degrees west, north ± 90 degrees east, north 30–35 degrees east, north 45–50 degrees east, north to north 5 degrees west, north ± 15 degrees east, and north 30–35 degrees west, the order named being the order of their relative abundance. Joint directions were taken with a compass and measured to the nearest 5 degrees. It was found further that certain joint directions especially characterized particular stretches of shore line, and the report adds:

> "The joints of this section, particularly those which strike N. 43 degrees E., are remarkable for the continuity of the individual planes. In some cases they may be observed extending on the shore line for the distance of 300 feet or more." . . .
>
> "The foregoing survey of the shore from the point of view of joint planes, makes it tolerably evident that there is some relation between the salients and reentrants of the coast line and the jointed character of the rocks. A study of the field would show the student that this is the case more effectively than it is indicated to him by the merely cursory account which we have given him."

Investigations of another great quarry region in Massachusetts by Crosby‡ show that the planes of jointing fall into approximately vertical and parallel series, which are ascribed by the author to crustal movements. Speaking of joints of the Churchill quarry in Quincy, Crosby says:

> "Although they trend in all directions, the prevailing trends, as throughout the quarry district, are approximately north-south or east-west, agreeing in this respect with the dikes."

---

* N. S. Shaler: The geology of cape Ann, Massachusetts. Ninth Ann. Report U. S. Geol. Survey, 1887–1888, 1889, pp. 529–611.

† E. R. Buckley: On the building and ornamental stones of Wisconsin. Bull. iv, Wisconsin Geol. and Nat. Hist. Survey, 1898, pp. 456–460, pl. lxix.

‡ W. O. Crosby: Geology of the Boston basin, vol. i, part iii. The Blue Hills complex. Occasional papers, Bost. Soc. Nat. Hist., IV, p. 340, pl. xvi.

Along the joint planes of the district faults were in many cases observed, the present structure being ascribed to folding and in part to faulting. The maps included with the paper show that the present formation boundaries have been largely determined by planes of faulting, and that the rock masses form a mosaic, which the author compares with the one described by Davis from the Connecticut valley.* In the areas lying within the uplands of southwestern New England, which the present writer has studied in detail, a correspondence of fault and joint directions has been established, and it is found that for both alike the dominant directions are near the meridian (north ± 5 degrees west); near the equatorial direction (north 85–90 degrees west), and in directions in part nearly bisecting them (north 50–55 degrees east and north 15 degrees east and north ± 34 degrees west and north ± 44 degrees west).

Cushing has described the joints and faults of Rand hill, in northern New York state.† He describes the master joints as trending principally along the meridian, or parallel to the equator. Other sets cut these directions at about 45 degrees. He adds, however, that many joints have been noticed which can not be brought into any of these sets, but that these are of much less importance. Of the faults he says:

> "The faults run in all kinds of directions. The greatest breaks have a general north and south trend, though they may depart from this as much as 45 degrees. Instead of being persistent in direction, they curve largely. The downthrow is always on the east side, with the result that progressively younger blocks appear as lake Champlain is approached. The general rude parallelism of these faults cuts up the region into a series of land slices. These are cross-faulted sometimes repeatedly as in the case of the block on the east of the Tracy Brook fault, but usually much less frequently. The cross-faults have a general east and west trend, but depart widely from that, and may or may not be normal to the main faults." . . .
>
> "The majority of the faults of the region are certainly normal (gravity) faults, and this is likely the case with all" (p. 73).

In the Adirondack region both Cushing and Kemp ascribe the valleys largely to faulting.‡ Professor Kemp says:

> "There is much reason to regard these valleys as chiefly due to faults and the mountain ridges as of the block tilted type, but in massive and metamorphic rocks this can not be as readily shown as in continuous and contrasted sediments. . . . The evidence leading one to ascribe many of the valleys to faults can be briefly summarized as follows:

---

*Loc. cit., p. 502.

†H. P. Cushing: Geology of Rand hill and vicinity, Clinton county. Nineteenth Annual Report State Geologist, New York State Museum, 1901, pp. 39–82, map.

‡J. F. Kemp: Preliminary report on the geology of Essex county. Rept. New York State Geol. Survey, 1893. Albany, 1894, pp. 438–440.

"(1) The 'passes,' . . . and many other narrow gorges with precipitous sides, evidently produced by fault scarps with a talus. Often a stream forms a waterfall in an especially narrow gorge, and the crushed and strained rocks are shown in excellent exposure. . . .

"(2) Many ridges have a comparatively abrupt face on one side and an even ascent on the other. Split Rock ridge in Westport and Essex is a good illustration. . . . If one climbs any of the hills in central Moriah and looks westward the horizon line of the mountains is a saw-toothed profile with a low ascent and a steep drop, many times repeated. . . .

"In many cases these faults afforded a start for lines of drainage which have now worn out the valleys to broad reaches and have masked their origin. The old scarps at present are rounded and worn down."

An area within the region described above by Kemp, and one where the lineaments are in correspondence with the controlling lineaments indicated on the map of plate 45 for the area of the central states, is shown in plate 47.

As a result of his extended study of joints throughout the state of Wisconsin, Buckley has made the following summary:*

"As will be seen in the accompanying map, the joints of the sedimentary rocks strike in four main directions. The prevailing general direction of the joints is N. E. and S. W. The other directions are N. W. and S. E., E. and W., and N. and S."

Insufficient as is the evidence for a satisfactory correlation of joints and faults within the area studied, it is at least accordant and strongly favors the view that master joints and master faults as well are not without relations to one another, even though separated by distances which may constitute an appreciable portion of the earth's circumference. The nearly meridional direction of jointing was found to be dominant in all the areas studied from Massachusetts to Wisconsin. The nearly equatorial and the two bisecting directions were the remaining directions of master joints in all save one of the districts examined—the Boston basin—and here the meridional and equatorial directions alone controlled. Observations by the writer in southwestern Wisconsin reveal there the same four directions of master joints. It is to be hoped that other investigators will give attention to the orientation of joint planes in connection with their study of local districts and put the results of their study on record.

Relation of Lineaments to the grander Features of the Earth

It must be evident that if the master lineaments within a large area reveal a control by disjunctive processes of the same type and referable to a single system or network, an explanation is called for which is far removed from local conditions of isostatic crustal adjustments. Lineaments which can be followed 1,000 miles or more as a definite and rather striking border of plateaux (*H*), which are individualized physiographically and geologically, must have an important relation to the orography of the earth as a whole. This idea has been brought out by Suess in connection with his study of an almost antipodal region in east Africa,where the dislocations observed were too extended to be explained by local conditions.* The stronger lines of displacement being there, as in many other regions, meridional or nearly so, Suess has suggested that they are connnected with a fracturing of the planet, considered as a whole. I quote:

---

* Loc. cit., p. 459.

> "These great lines of fracture showing such a peculiar arrangement in space, so far as our present knowledge of them extends, do not allow of a comparison with the fault network arranged peripherally and radially to a trough-like depression; as, for example, the depressed areas of southern Germany and northern France. . . . The considerable part of the earth's meridian included within the area shows that we have here to do with dislocations which are at least of the order of the furrows upon the moon, if this be a very distant comparison." (Page 135.)
>
> "The occurrence of such great meridional clefts might easily lead to the view that there is present throughout a tendency toward meridional fissuring, like the fracturing of the planet in the direction of its meridian; and indeed, so much the more, since the lines of the Laccadive and Maldive islands and the greater number of meridional fractures in the faulted country of the Basin range of North America appear to confirm such an hypothesis." (Page 139.)

Even more worthy of consideration in this particular are papers by Baron von Richthofen, dealing with the geomorphology of eastern Asia,† in which it is clearly shown that the grand features of the entire Pacific coast of Asia are arranged in a system or network made up of a series of tilted plateau-like blocks, the arc-like boundaries of which give form to the great plateau area, as well as to the Asiatic coast line and to the festoons of islands which fringe it. According to v. Richthofen, the meridional and diagonal series of lineaments are in each case tectonic lines of displacement; the equatorial series which joined to the meridional ones produce the arcs, are in part explained by fold structures. The individual tectonic lines of the series are in some cases 700 miles or more in length, while continuous zigzagging series nearly cross the continent.

---

*Eduard Suess: Die Brüche des östlichen Afrika, Beiträge zur geologischen Kenntniss des östlichen Afrika, by v. Höhnel, Rosinal, Toula, und Suess. Part iv, pp. 135, 139. Special reprint from the Denkschriften d. math. naturw. klasse d. k. Akad. d. Wiss., Wien.

†Geomorphologische Studien aus Ostasien, i–v. Sitzungsber. d. königl. preuss. Akad. d. Wissensch. z. Berlin, 1900–'04. Partial translations have appeared in consecutive numbers of the American Geologist, beginning August, 1904, under the title, Tectonic Geography of Eastern Asia.

Of interest also in this connection is the paper by Prinz,[*] which deals with the cardinal orientation of the grand features of the earth and of the other planets in the solar system. Prinz finds that the earth, and so far as their maps permit generalization, the planets Mercury, Venus, Mars, and Jupiter, betray grand features arranged in two nearly rectilinear sets running northwest-southeast and northeast-southwest respectively, with an intermediate set directed nearly along the meridians. Following Schiapparelli, who has furnished the remarkable maps of Mars and Mercury, he attributes these networks to geotectonic forces affecting the planet as a whole, and in the case of the earth he sees evidence of torsion operative between the northern land and the southern sea hemispheres along the twin plane of Green in such a manner as to produce systems of joints analogous to those brought out in glass by the experiments of Daubrée and Tresca.

In a paper dealing with the symmetry of the northern hemisphere, Professor Suess has said :[†]

> "It now appears also that the separation of the movements into tangential (folding) and vertical (sinking) motions must be much more sharply held than before. The relation of the Atlantic ocean, which is younger than those chains, to these latter makes this clear."

It follows, from the conception of the zones of fracture and flowage within the lithosphere, that under the causes which operate to produce crustal shortening, the stresses will be relieved within the outer shell by fracture at the same time that adjustment is secured by folding in the more deeply buried portions. With the progress of degradation the folded portions of the crust, so far as they are uncovered by such a process, will be successively brought within the zone of fracture; and under the operation of forces of the same type as those which produced their folds will now be deformed by fracture. Such deformation by fracture will be necessarily superinduced on the earlier developed fold structures, and particularly when accompanied by displacement should most profoundly modify the surface architecture, both before and subsequent to denudation. In a region in which both folds and normal faults are present, the faults must be the later and hence the more likely to influence the physiographic development.

Considering the bearing of the above survey, it is interesting to read the summary by Russell[‡] after his correlation study of the Newark areas, which are scattered from one end to the other of the area here examined.

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[*] W. Prinz: Sur les similitudes que présentent les cartes terrestre et planetaires (Torsion apparent des planètes). Ann. de l'observatoire royale de Bruxelles, 58th year, 1891, pp. 304–337.

[†] Sitzungsber. d. k. k. Akad. d. Wissensch. in Wien., vol. cvii, abth. i, 1898. Translation by Emerson in Bull. Geol. Soc. Am., vol. 11, 1900, p. 105.

[*] Bull. 85, U. S. Geol. Survey, 1892, p. 98.

> "An examination of the entire system shows that faulting is as important an element in the structure of the Atlantic Coast plain as it is in the Great basin. These two regions have this important difference: In the Great basin fault scarps stand in relief and form mountain ranges, while along the Atlantic Coast the relief has been subdued by erosion, and for the most part a featureless plain takes the place of the mountain uplifts that would otherwise appear.
>
> "It is to be supposed that the faults traversing the Newark rocks are but a portion of a great system which affects a large part, and perhaps the entire region, of metamorphic rocks, in the midst of which remnants of the Newark system have been preserved."

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NANTUCKET SHORELINES. II

BY F. P. GULLIVER

(Presented before the Society January 1, 1904)

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SCOPE OF THE PAPER

During the past year the writer has continued his studies of the recent changes in the shorelines of the island of Nantucket, and the results of such study are given in this paper. Details of the changes are presented in the following areas: Great point, Coskata, Haulover break, Surfside, Maddaket, Smith point, Brant point, Nantucket harbor, and Coatue (see figure 1).

This second paper on Nantucket shorelines describes some of the detailed work of 1902–1903. The first point considered will be the long arm projecting from the north of the island toward Monomoy point, which projects southward from the elbow of cape Cod.

GREAT POINT

Great point and Monomoy are two great masses of sand worn respectively from the east side of Nantucket and the east side of cape Cod, carried along by the action of the waves, tides, and currents to the north from Nantucket, to the south from cape Cod, and then blown up by the winds to form these great sand spits, which threaten to close the entrance of the inland waterway on the eastern coast of the United States through Nantucket and Vineyard sounds. This danger was pointed out by Professor Henry Mitchell,* who says:

> "It looks as if the sea would soon break from Monomoy to Nantucket on the summit of the circus that is formed by Pollock Rip, Great Round Shoal, and Great Point Rip, with their connections."

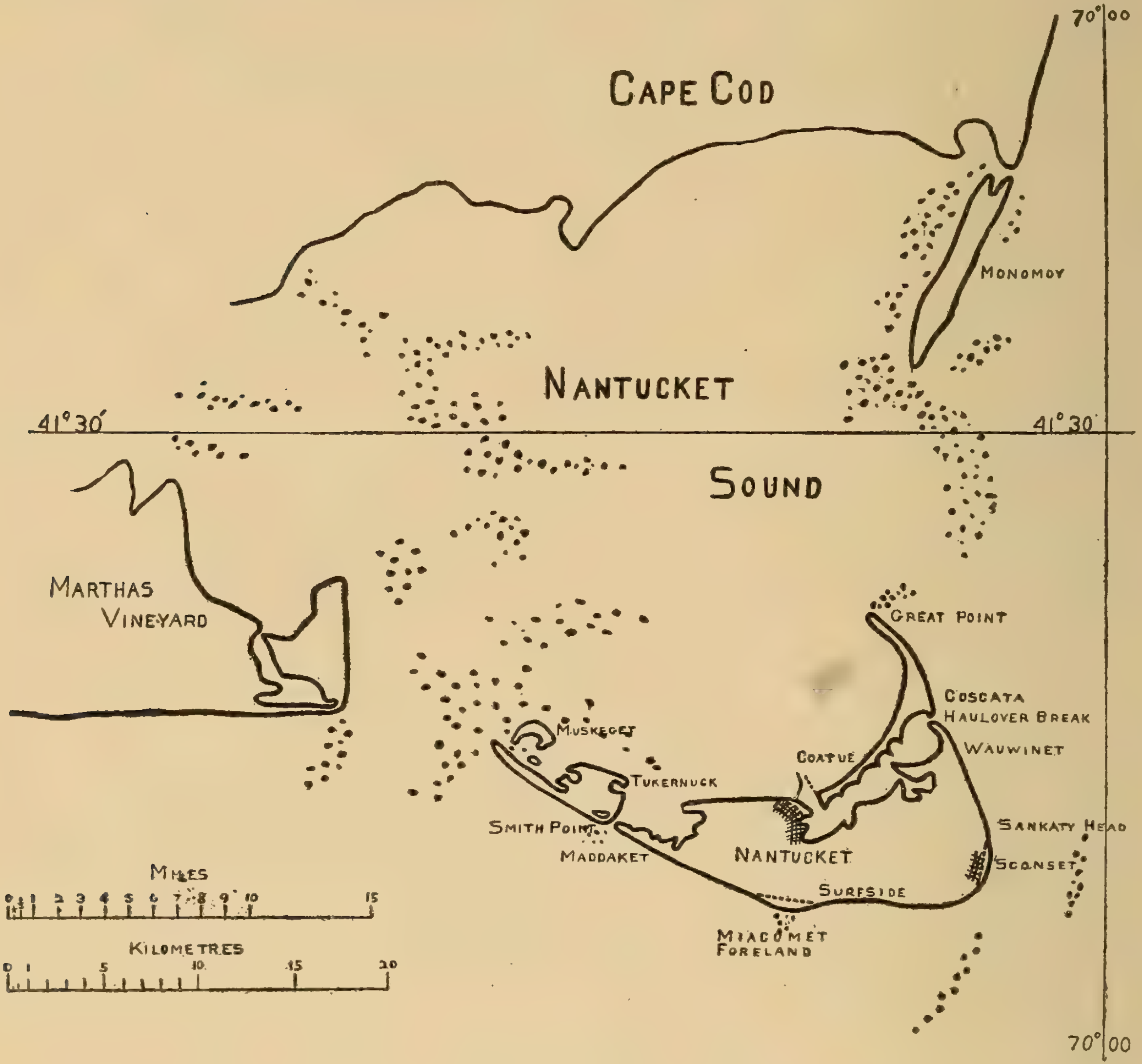
70° 00
CAPE COD
MONOMOY
NANTUCKET
41°30′
41°30
SOUND
MARTHAS VINEYARD
GREAT POINT
COSCATA
HAULOVER BREAK
WAUWINET
MUSKEGET
TUKERNUCK
COATUE
SMITH POINT
MADDAKET
NANTUCKET
SANKATY HEAD
SCONSET
SURFSIDE
MIACOMET FORELAND
MILES
0 1 2 3 4 5 6 7 8 9 10 15
KILOMETRES
0 1 5 10 15 20
70° 00

FIGURE 1.—*Nantucket and adjacent Areas.*

In 1887 Professor Mitchell began to study the movements of sand along the shoals off Great point and Monomoy.† He based his work on his studies of the tidal movements in New York harbor, and compared the circus of shoals outside of the Monomoy entrance to the New York deposits, and says:

"We have at the entrance to the Vineyard sound, at least in embryo, the outside and inside bars of an 'inlet' (as an opening through the sandy cordon of our southern coast is called), but, as we shall see, the conditions at this opening are peculiar. At the 'inlet' the outer bar represents what is gone from the sandy cordon at the opening, while the inside bar, sometimes called the 'swash,' is the ground-up sand delivered by the breakers to the flood current and dumped at the point where the flood current loses its power in the lagoon. The circus of shoals outside of the Monomoy entrance is an encroachment from an independent source, as the comparative map shows."

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* A report on Monomoy and its shoals. U. S. Coast and Geodetic Survey. Appendix no. 8, 1886.

† The movements of the sands at the eastern entrance to Vineyard sound. Appendix no. 6, 1887.

He considered that "the net effect is a westwardly movement," and that it was necessary to study carefully the action along the cliff on the shore and on the bottom in order to settle whether the shoals were in danger of obstructing navigation at this point or not.

In order to get at any estimate of the time necessary to build these sand spits into one continuous mass of sand, which the writer has named a tombolo,* it is important to study in the greatest detail possible the method of the upbuilding of the sand. Although there may be no immediate danger to the commerce of the country at this particular point, there may be places at other points along the coast where the facts obtained by the detailed study of the action of the sea along Great point and Monomoy will enable engineers to prevent or delay the closing of important waterways.

As shown by various measurements made by the U. S. Coast and Geodetic Survey along the east side of Nantucket and cape Cod, there has been within the last fifty years a decided cutting back by the sea of the coast line. From 1846 to 1887 there has been a retreat of the shoreline between Sankaty head and Great point, increasing in amount from nothing in these two areas to a maximum of 300 feet at Coskata island.†

While Monomoy ‡ has grown southward in a marked degree, Great point has remained comparatively stable in its position with reference to its distance north from any fixed point in Nantucket island.§ There have, however, been decided changes along the shoreline of Great point within the last few years, although the extreme northern extension of Great point is practically the same today as it was fifty years ago. It is possible that the breaking through of the sea at the old Haulover, at the head of the harbor, may have influenced these changes somewhat. This point will be kept in mind in future studies, but at the present time the writer does not wish to express an opinion.

On the east side of Great point the sea is cutting into the sand which forms Great point. On the west side of Great point there was discovered a building up of the sand a short distance south of Great Point light during the summer of 1903. The sand came around the north of Great point and was built up in front of the west shoreline as a low offshore bar inclosing a narrow lagoon (plate 48, figure 1). In August, 1903, there were four of these lagoons and sand bars observed overlapping one another. Apparently the outgrowth was progressing farther and farther to the south. It is proposed to continue observing these bars and lagoons during succeeding years.

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* Shoreline topography, Proc. Am. Acad. Arts and Sciences, vol. xxxiv, 1899, p. 189.

† H. L. Marindin: U. S. Coast and Geodetic Survey. Appendix no. 6, 1892, p. 245.

‡ H. Mitchell: U. S. Coast and Geodetic Survey. Appendix no. 9, 1873.

§ H. L. Marindin: U. S. Coast and Geodetic Survey. Appendix no. 6, 1892, p. 244.

COSKATA

The breaking through of the Haulover in the winter of 1896–'97 caused the sea to attack the land south of Coskata pond at the head of Nantucket harbor. This cutting revealed the fact that to the southeast of Coskata pond there was formerly an island made up of clay and glacial gravel, which the writer has called Coskata island (plate 48, figure 2). This area has been so covered with dense brush that it has formerly been considered as part of the sand built up by the sea, but by the exposures made since the formation of the Haulover break, the true character of this oldland island has been clearly shown (plate 49, figure 1).*

To the north of Coskata pond there is now a small remnant of another island, not yet consumed by the sea, which the writer would call Folger island, from the name of the family who lived on the sheep farm situated at this point. Undoubtedly this island and Coskata island formerly extended much farther to the east, and they have been cut back by the sea, together with the east coast of Nantucket island extending from Wauwinet to 'Sconset. The bar connecting Coskata with Nantucket island at Wauwinet was a completed tombolo, over which the sea broke in a great storm in December, 1896.

The writer has commenced a comparison of the old maps and records of the Coskata region, and hopes at some future time to be able to present more in detail the history of Coskata and Folger islands.

HAULOVER BREAK

Within the memory of the oldest inhabitant of Nantucket there has been a completed tombolo connecting Coskata island with the oldland of Nantucket at Wauwinet, and as far as the writer knows there is no local tradition of any opening in this tombolo between Wauwinet and Coskata since the first settlers began to displace the Indians on the island of Nantucket.†

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*On the geological map of Nantucket by Professor Shaler a portion of Coskata island is colored as till. Bulletin 53, 1889, U. S. Geol. Survey.

† Since this was written the writer has heard of an old map which shows an opening.

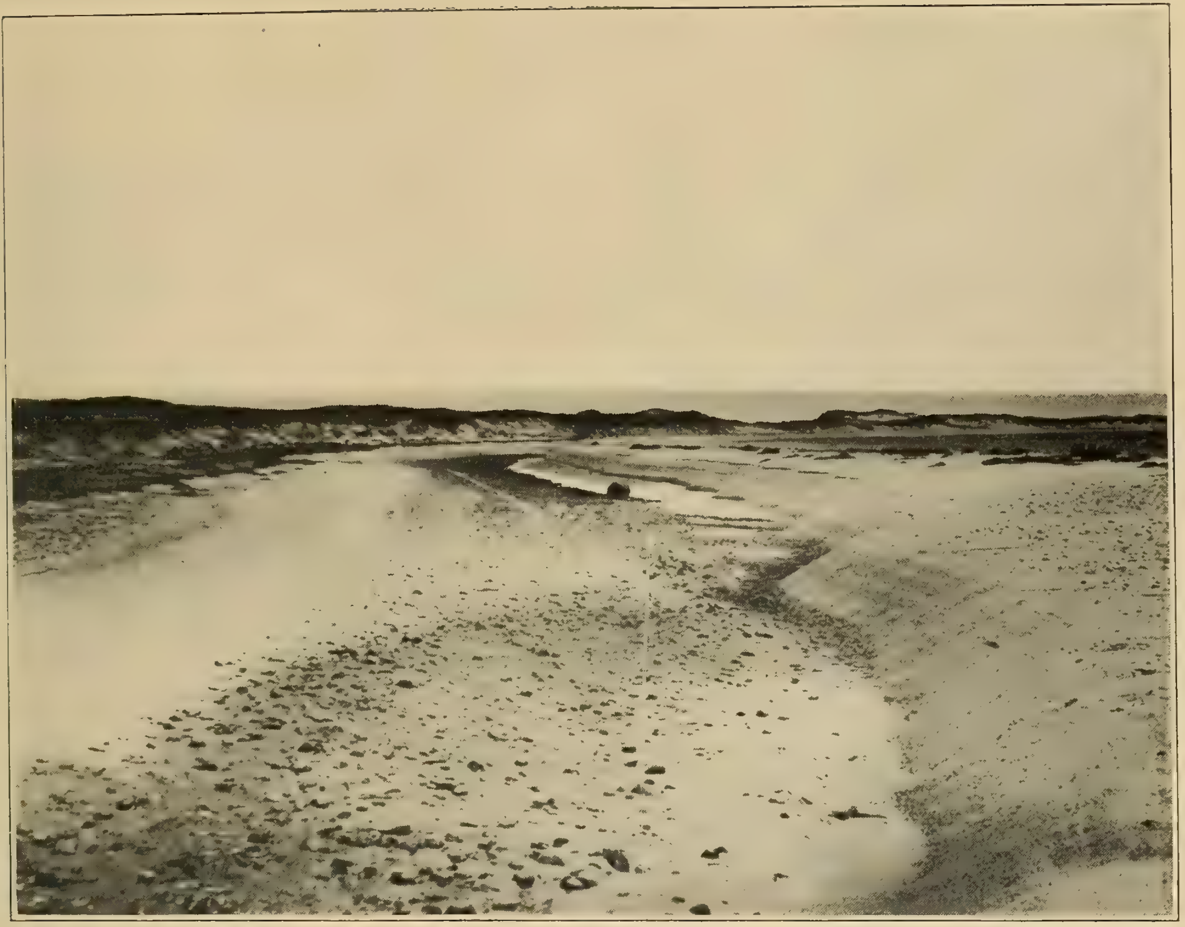

FIGURE 1.—AGGRADING SHORELINE, LOOKING SOUTHEAST, HALF A MILE SOUTH OF GREAT POINT LIGHT

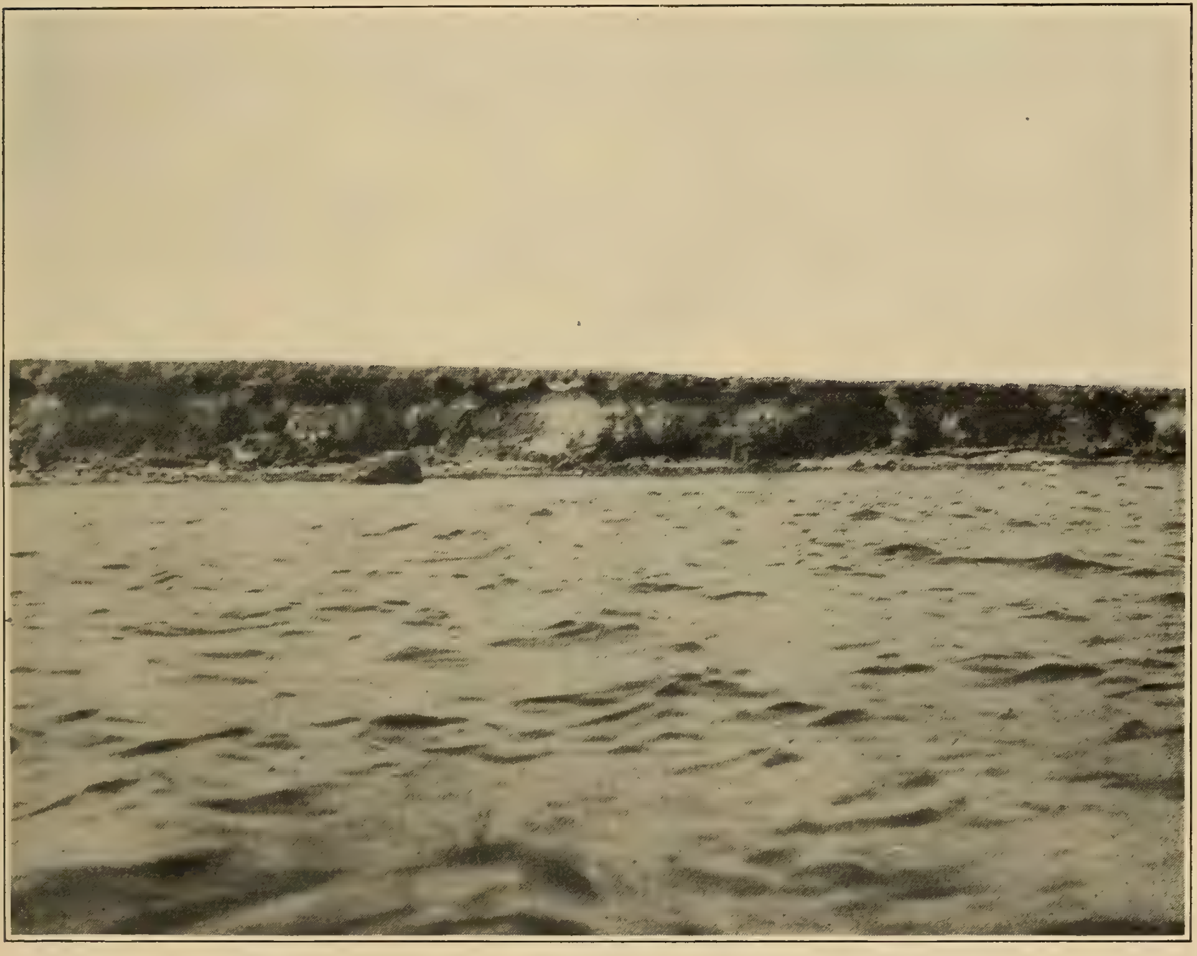

FIGURE 2.—COSKATA ISLAND, AUGUST 6, 1902

AGGRADING SHORELINE AND COSKATA ISLAND

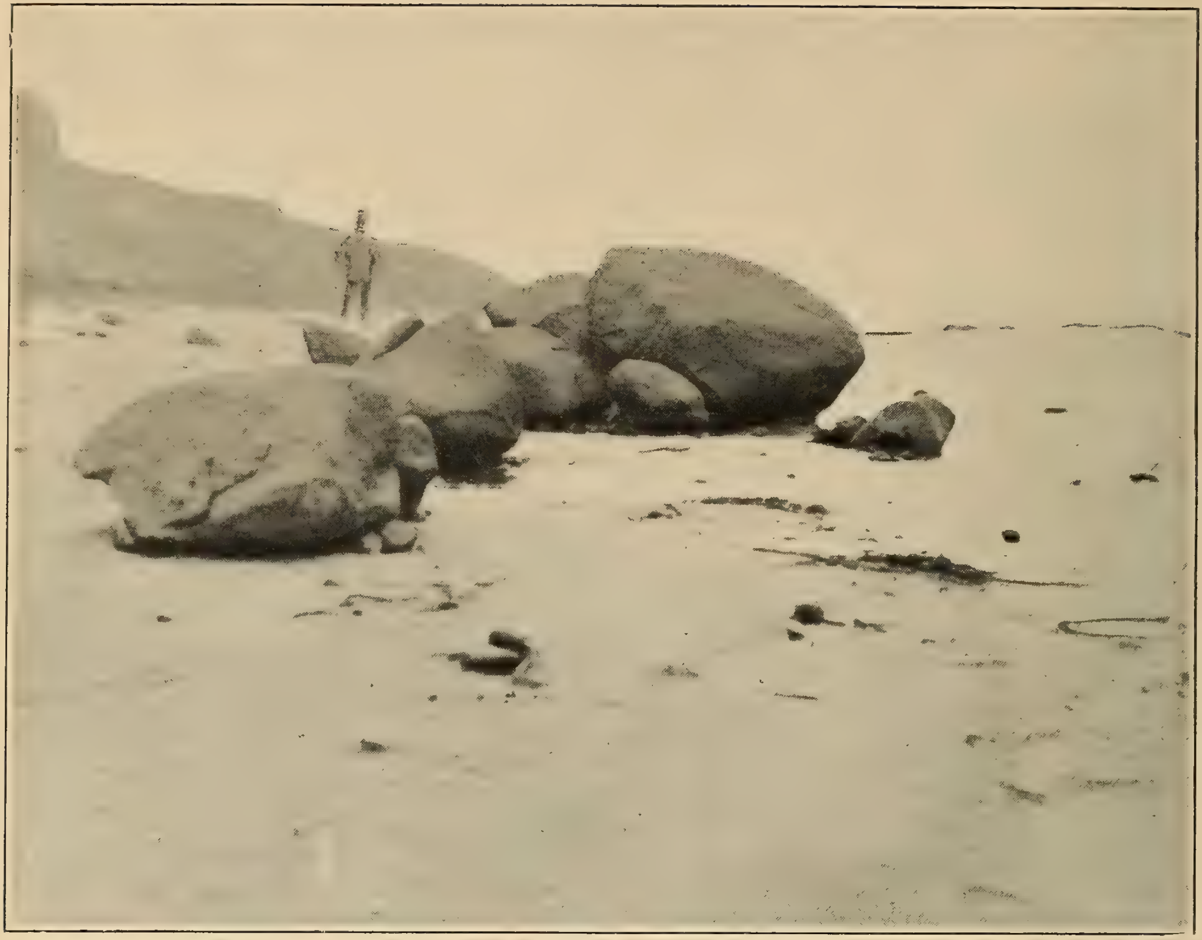

Figure 1.—Boulders from Coskata Island, August 6, 1902

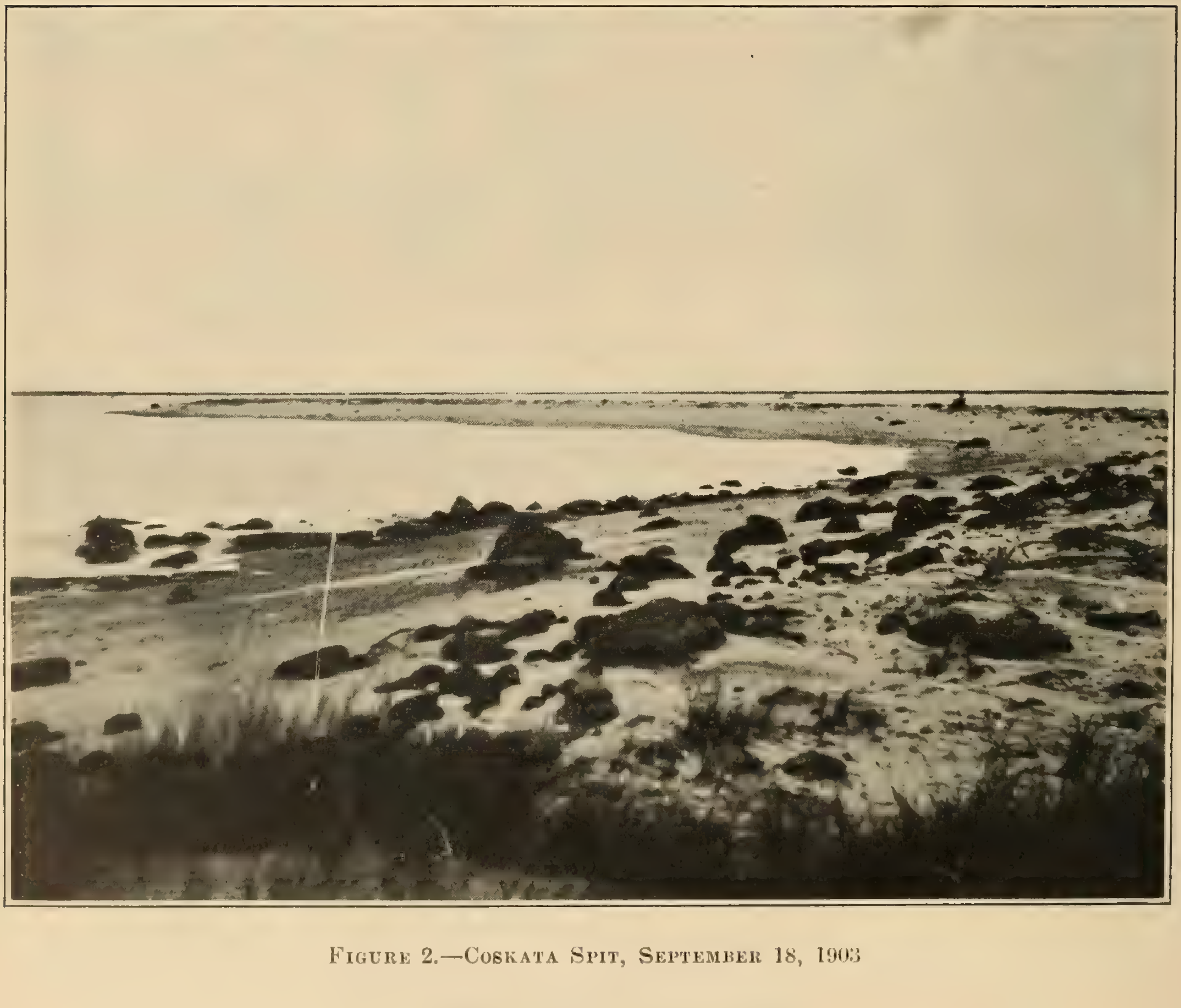

Figure 2.—Coskata Spit, September 18, 1903

COSKATA SPIT AND BOULDERS

A vague tradition comes to the writer that at one time it was possible to sail from the town of Nantucket up the harbor and then go around Wauwinet and Squam head into Squam and Sachacha ponds "without going out into the open ocean." This could only be possible if the tombolo was first built as a bar offshore outside of Squam head. The writer has failed to find any confirmation of this tradition. It is quite possible that it was so, but as far as the present studies of this region have been carried there is no proof of its truth. Of course, it is possible that there might have been an opening in the tombolo north of Wauwinet through which a sailboat could go, and that there was another opening in the bar which now closes the east side of Sachacha pond into which the boat may then have sailed. A third possibility is that the tradition may refer to a trip made in a dory which was hauled across the tombolo at the "Haulover" north of Wauwinet, and thence proceeded through the open ocean outside of Squam head and into Sachacha pond.

For two or three years previous to 1896, according to Captain Chase, who was stationed at the Coskata Life Saving station at the time, the waves broke over the tombolo between Wauwinet and Coskata in any heavy easterly gale. During the fall of 1896 there were several unusually heavy storms, and finally, on December 17, 1896,* the sea cut a narrow channel across the tombolo at a point which had been used by the fishermen for many years as a place for hauling small boats from the head of the harbor to the open ocean.

This stage is represented in the second diagram of the series of drawings on plate 50, showing the progressive changes in the form of the tombolo from 1896 to 1903. The drawing marked 1890 is from the Coast Survey planetable sheets surveyed in 1888 and 1890 and gives the form of the inner and outer shorelines as well as the fathom lines east and west of the tombolo (plate 50, figure 2). This condition remained practically the same until the fall of 1896. The second drawing is based on the preceding and altered according to sketches made by Captain Sidney Fisher a few weeks after the break occurred (plate 50, figure 3). The third drawing, marked April, 1897, is also made from drawings made by Captain Fisher (plate 50, figure 4). Both of these drawings show that at first there was a decided turning in of both ends of the tombolo at the break, leaving a shallow body of water between the two hooked spits.

A good deal of sand must have been carried in through this opening and deposited in the deep water at the head of the harbor, for we find in the hydrographic survey made by the U. S. Coast and Geodetic Survey, October 4–11, 1897, from which the fourth drawing in the series marked 1898 is made, that the soundings are considerably shallower than those given by the first map in the series (plate 50, figure 5). From the study of this hydrographic survey we see that the form of the tombolo on the ocean side below the first fathom line had changed but very slightly since the break occurred. The great change is seen above the first fathom line on the ocean side, where the two spits were much worn away during the summer of 1897. The opening between the two broken ends of the tombolo was at this time more than a quarter of a mile wide, although the depth at any point between the two spits was not more than 6 feet. It is also seen that the sand blown along from the southeast along the Wauwinet bluff, and from the north along the bluff of Coskata island, was carried through this opening and deposited in a tidal delta on the inside of the tombolo at the head of the harbor. For several years there was but little change in form of the broken tombolo or of the offshore and inshore bottoms.

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* H. S. Wyer: Sea-girt Nantucket, p. 18.

The fifth drawing shows the conditions in 1901 (plate 50, figure 6). This is a compilation from information given by the U. S. Coast and Geodetic Survey, the engineers of the War Department, various local sources of information, and observations by the writer. It will be seen that by this time a good deal of sand had come from the southeast and was built into the south or Wauwinet spit. Coskata spit had been worn away slightly at the point and broadened farther north.

Between the summer of 1901 and the summer of 1902 there was a marked northern extension of the Wauwinet spit and a decided cutting back of the Coskata spit (plate 50, figure 7). It was during this time that the great erosion took place on the southern coast of Coskata (see plate 48, figures 2, and plate 49, figure 1). The form of Coskata spit on the drawing marked 1902 is from measurements made by Dr Benjamin Sharp and the writer on August 6, 1902. The form of this spit was changing constantly during this cutting back of the Coskata end of the tombolo. The opening was still nearly a quarter of a mile wide.

The seventh drawing gives conditions in July, 1903, and is based largely on a survey made under the direction of Captain C. E. Gillette, of the Engineer Corps of the United States Army (plate 50, figure 8). It will be seen by inspection of this drawing that the Wauwinet spit has grown much farther to the northeast, and that it points farther in toward the head of the harbor than it did in previous years. There were many changes observed by the writer in the form of both of these spits during the summer of 1903. At one time in August the northwest point of the Wauwinet spit formed an island, the waves having broken through at the narrowest point of the spit, about one-sixth of a mile from the end. This was again closed and again broken open later in the summer. The

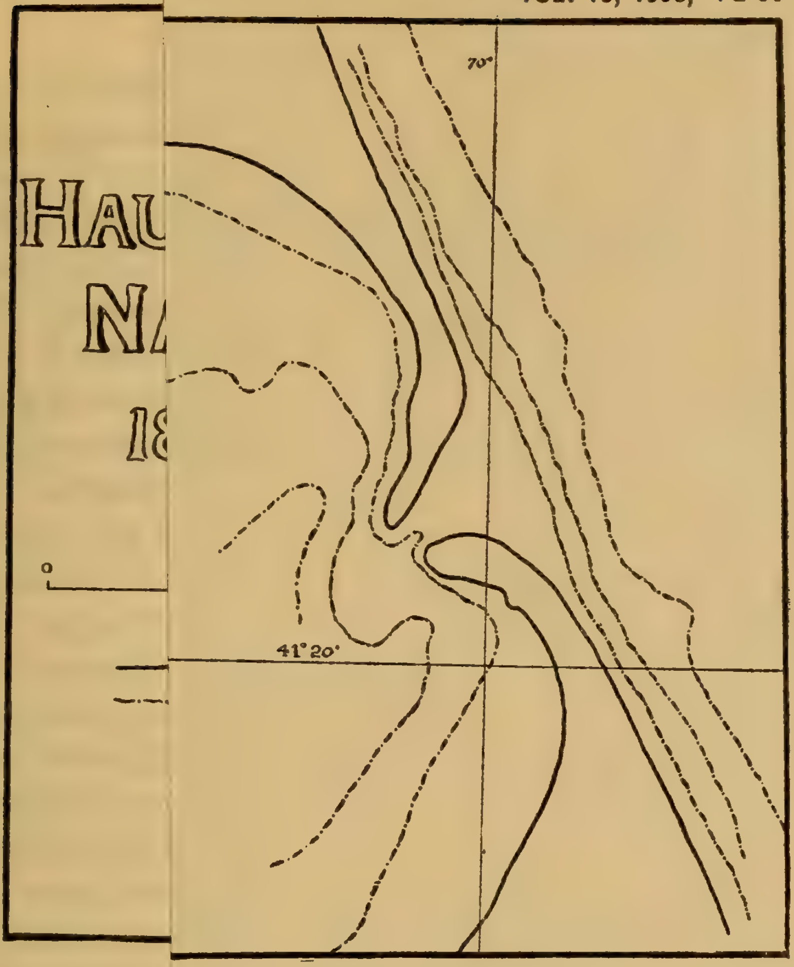
HAU
NA
18
0
70°
41° 20'

FIGURE 4.—AREA AS MAPPED IN APRIL, 1897

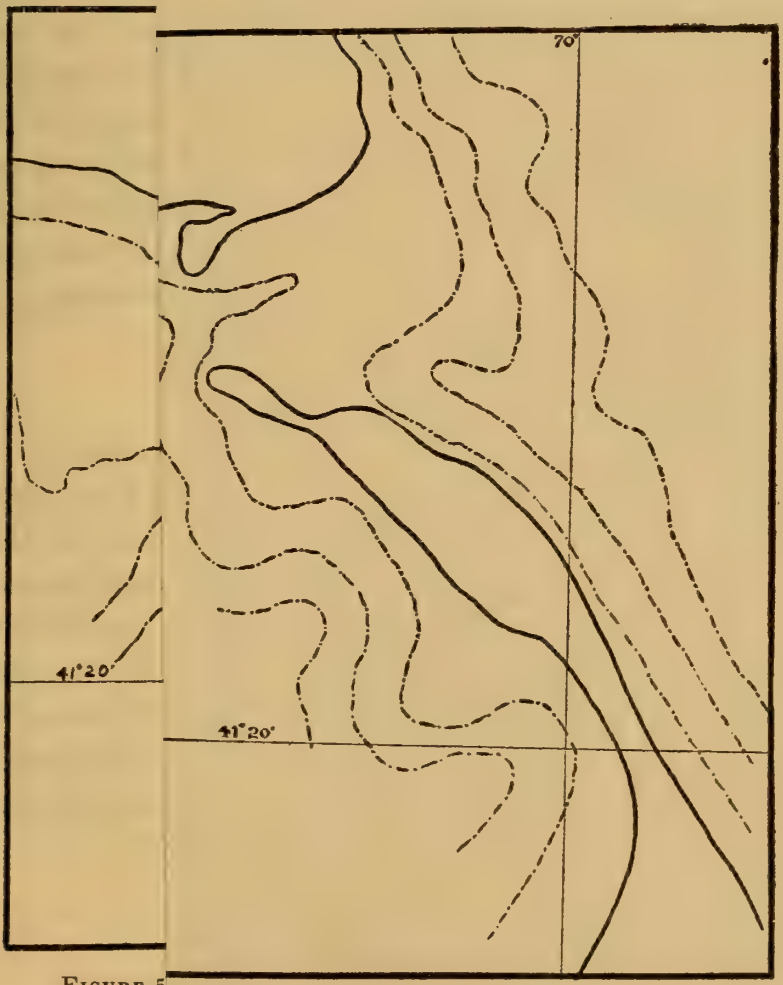
70°
41° 20'
41° 20'

FIGURE 5

FIGURE 8.—AREA AS MAPPED IN JULY, 1903

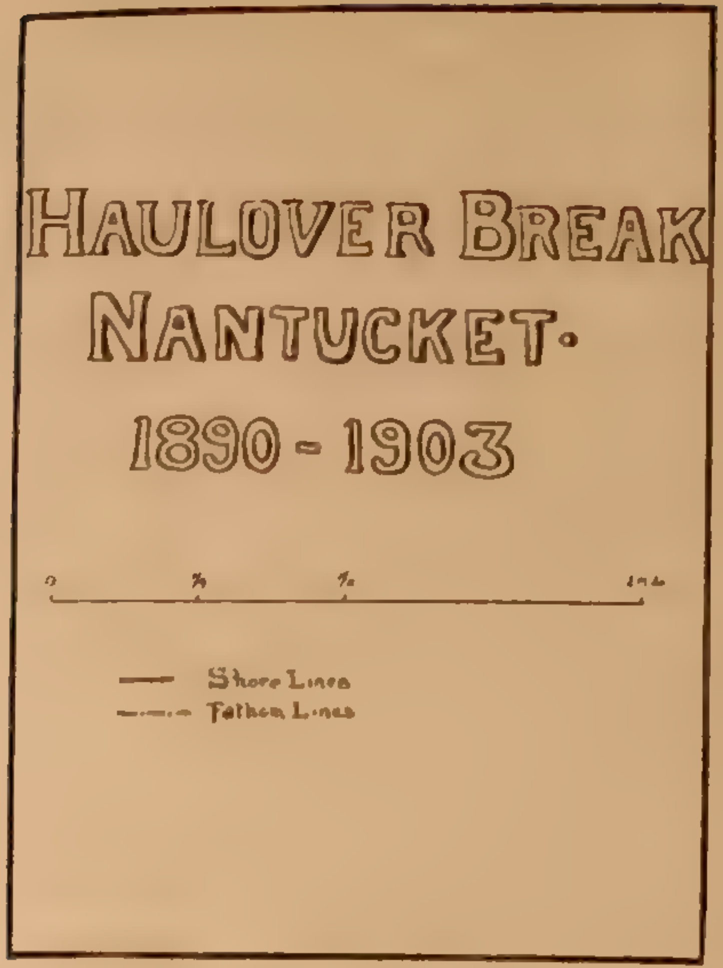
HAULOVER BREAK
NANTUCKET·
1890 - 1903
0
¼
½
1 mi
Shore Lines
Fathom Lines

FIGURE 1.—TITLE

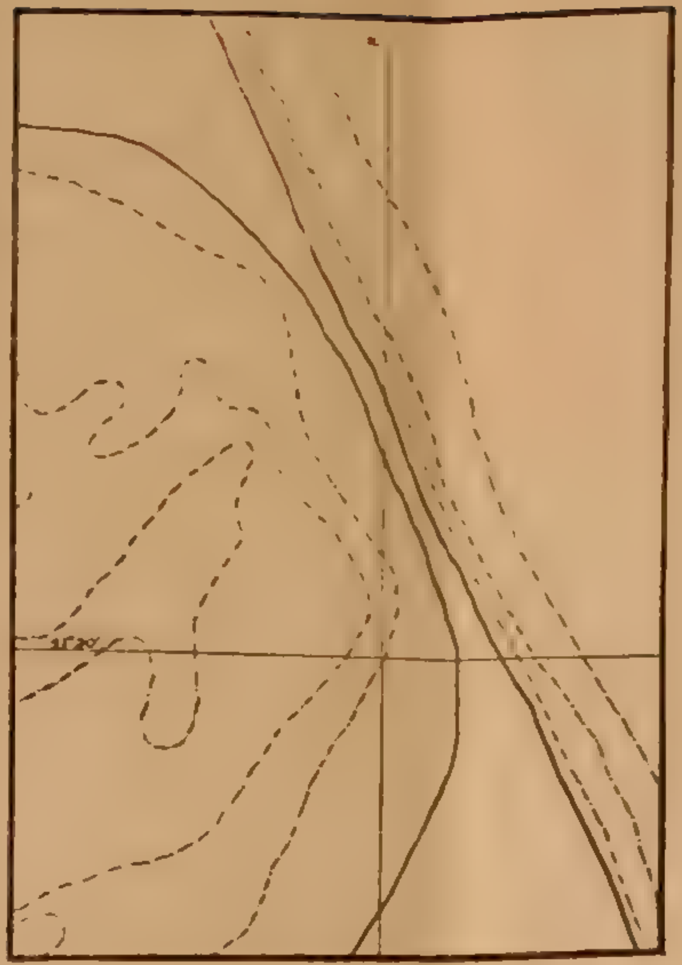

FIGURE 2.—AREA AS MAPPED IN 1890

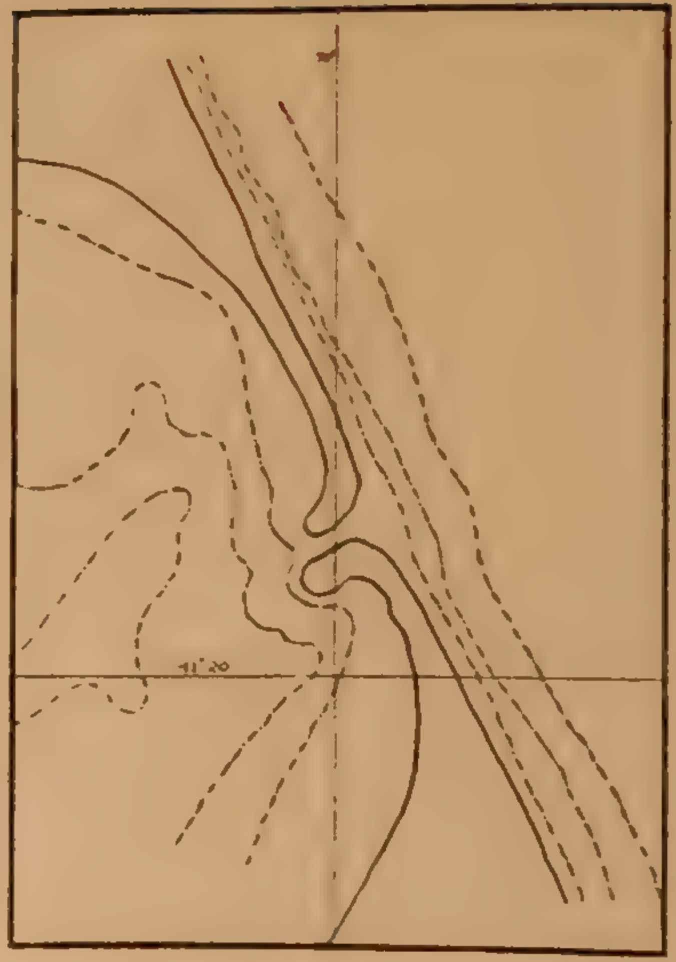

FIGURE 3.—AREA AS MAPPED IN DECEMBER, 1896

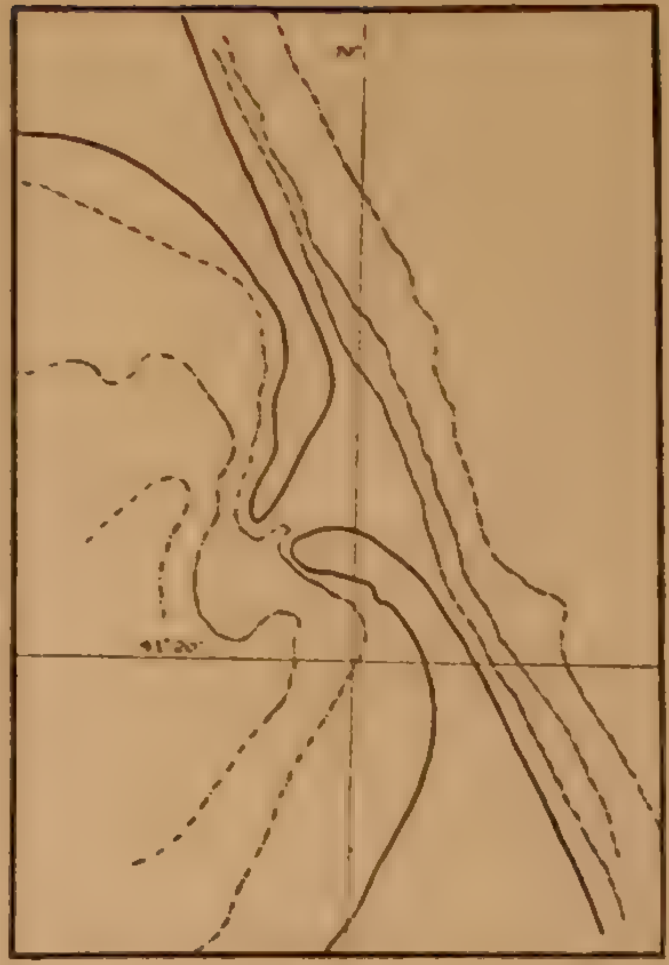

FIGURE 4.—AREA AS MAPPED IN APRIL, 1897

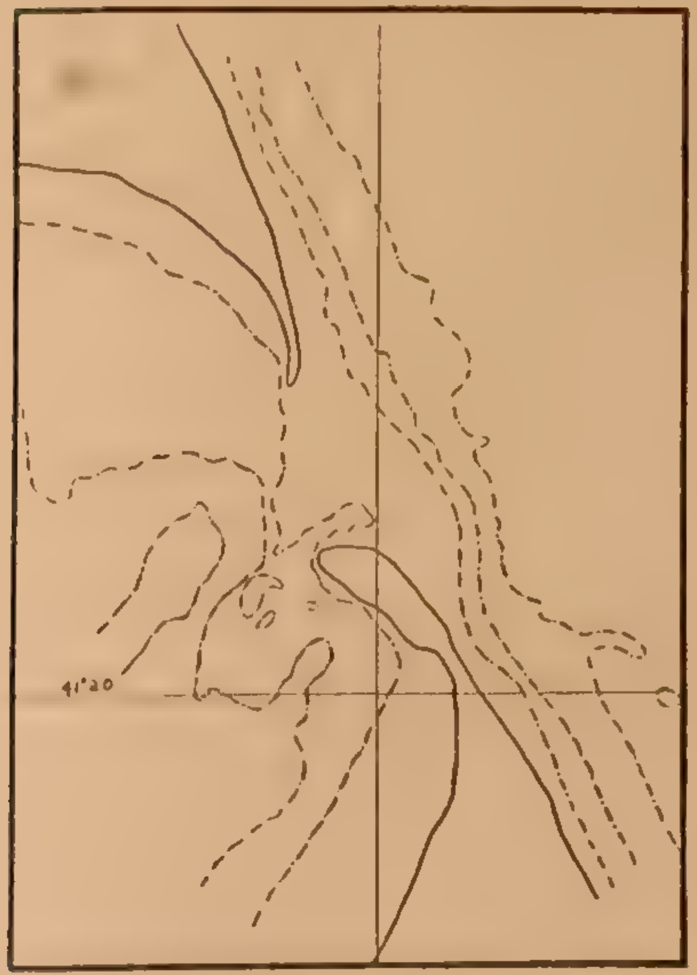

FIGURE 5.—AREA AS MAPPED OCTOBER 4-11, 1897

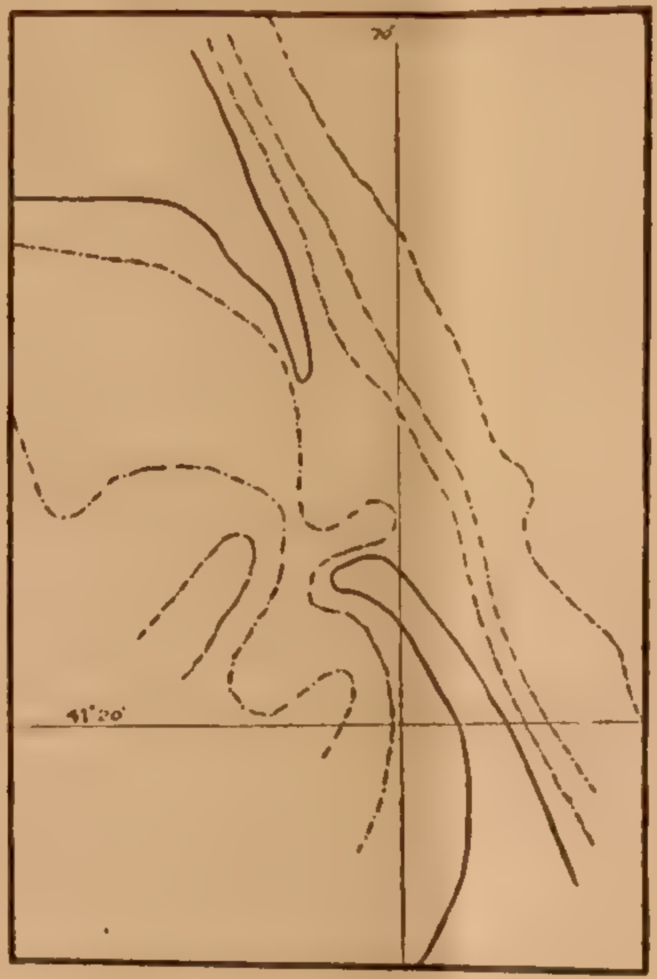

FIGURE 6.—AREA AS MAPPED IN 1901

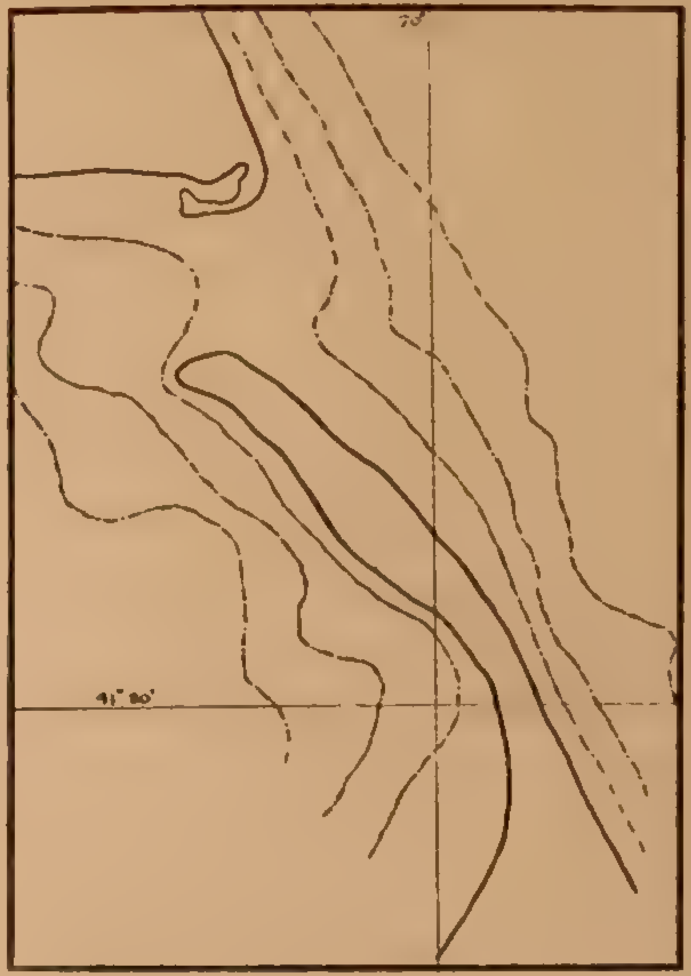

FIGURE 7.—AREA AS MAPPED AUGUST 6, 1902

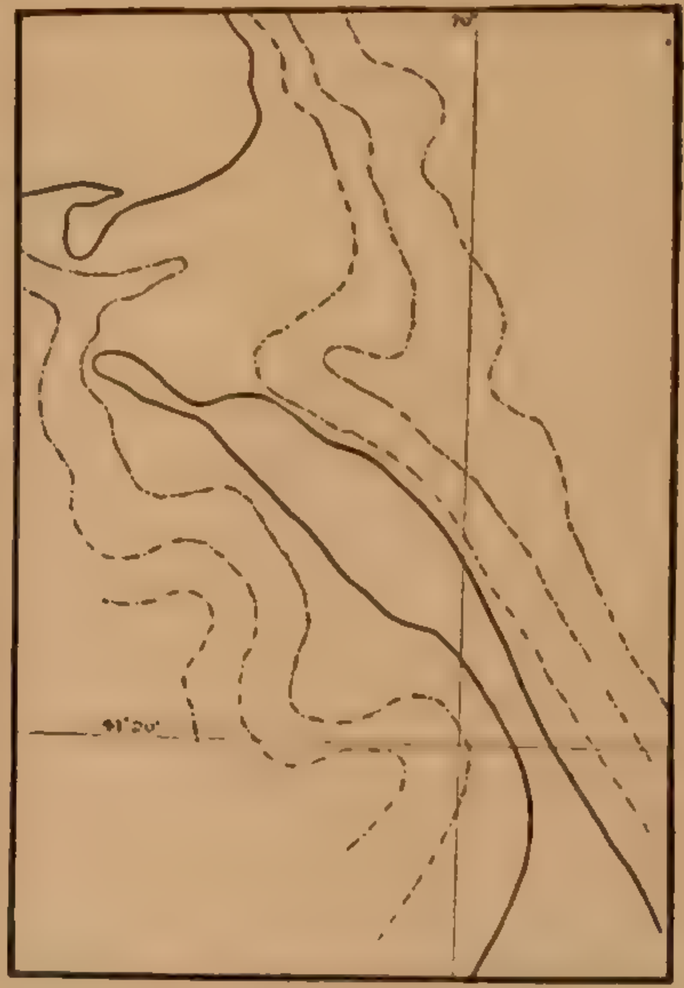

FIGURE 8.—AREA AS MAPPED IN JULY, 1903

DIAGRAMS OF TOMBOLO FROM WAUWINET TO COSKATA DURING PERIOD 1890-1903

spit from Coskata island shifted many times during the year. In July, 1903, it pointed well into the head of the harbor, leaving the southeast corner of Coskata island exposed to the erosion of the ocean waves. During the past year this portion of Coskata island was cut back very rapidly, great masses of the peat from the oldland swamps being hurled up by the waves and torn to pieces and washed out into the ocean and along the shore (plate 49, figure 2).

The three-fathom lines shown on this drawing for 1903 were drawn by the writer from soundings given by Captain Gillette. They show a much broader mass of sand between the two-fathom line on the ocean side and the two-fathom line on the harbor side than in any previous year since the break. This shows that the ocean is bringing, mainly from the southeast, a large amount of sand to fill up this opening. It is on account of this increased distance across that portion of the tombolo under water that sailboats have found it more and more difficult to sail through the opening during the last two years. It is undoubtedly only a question of time, and probably only a short time, before the sea will have completely closed up this opening. The next few years are a very critical period for accurate observation in order to see just how the sea goes to work to form a completed tombolo, joining an island to the mainland. From the work done by the army engineers it appears that the breaking through of the tombolo at the Haulover has not caused any perceptible change in the depth of water at the entrance to the harbor of Nantucket.* The sand brought in through the break has all been deposited immediately inside the two spits, and the great mass of the tombolo under water is preventing any marked change in the currents in the harbor. The sand bars and shoals in the harbor between Coatue and the northern shore of Nantucket have remained practically unchanged since 1896.

SURFSIDE

On the south shore of Nantucket the sea is steadily eating its way into the land, and the sand worn away from the outside is carried around and built into the bar on the north, forming the tombolo, which extends from Wauwinet past Coskata island out to Great point, and is also carried to the northwest, forming the extension of Smith point, Muskeget island, Muskeget, Tuckernuck, and other shoals. The smooth outline of the shoreline on the east and south of Nantucket, as shown on the Coast Survey charts of 1846, would indicate that this shoreline was mature and that the sea would cut it back as rapidly as possible. During the last half century, however, there have been two forelands built out in front of this maturely developed shoreline. One of these forelands is the low bathing beach in front of 'Sconset bluffs, and the discussion of its formation will be left to a later paper. The other is what the writer would call Miacomet foreland, which has been built out in front of Weweeder and Miacomet ponds, to the west of the Weweeder Life Saving station, about 3 miles south of the town (figure 2).

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*Annual Report of the Chief of Engineers for 1903, p. 90.

In September, 1903, the writer made a planetable survey of this foreland, marking several stations on the foreland and on the former shoreline with iron pipes sunk in the sand, to enable accurate measurement of the advance and retreat of the shoreline to be made in this region. This planetable map, showing the location of these fixed stations, is here reproduced on a scale of 1 : 10,000. The line *A–B* was measured with a tape and found to be 1,179.34 feet. These two stations, *A* and *B*, were occupied by the planetable and the other stations shown on the map were located by graphic triangulation. Offsets to the shoreline were measured at many points, so that the high and low tide lines, as given on this map, are practically correct for the scale. The detailed surface form, showing dune ridges and hollows between the dunes, was obtained by means of many intermediate planetable stations.

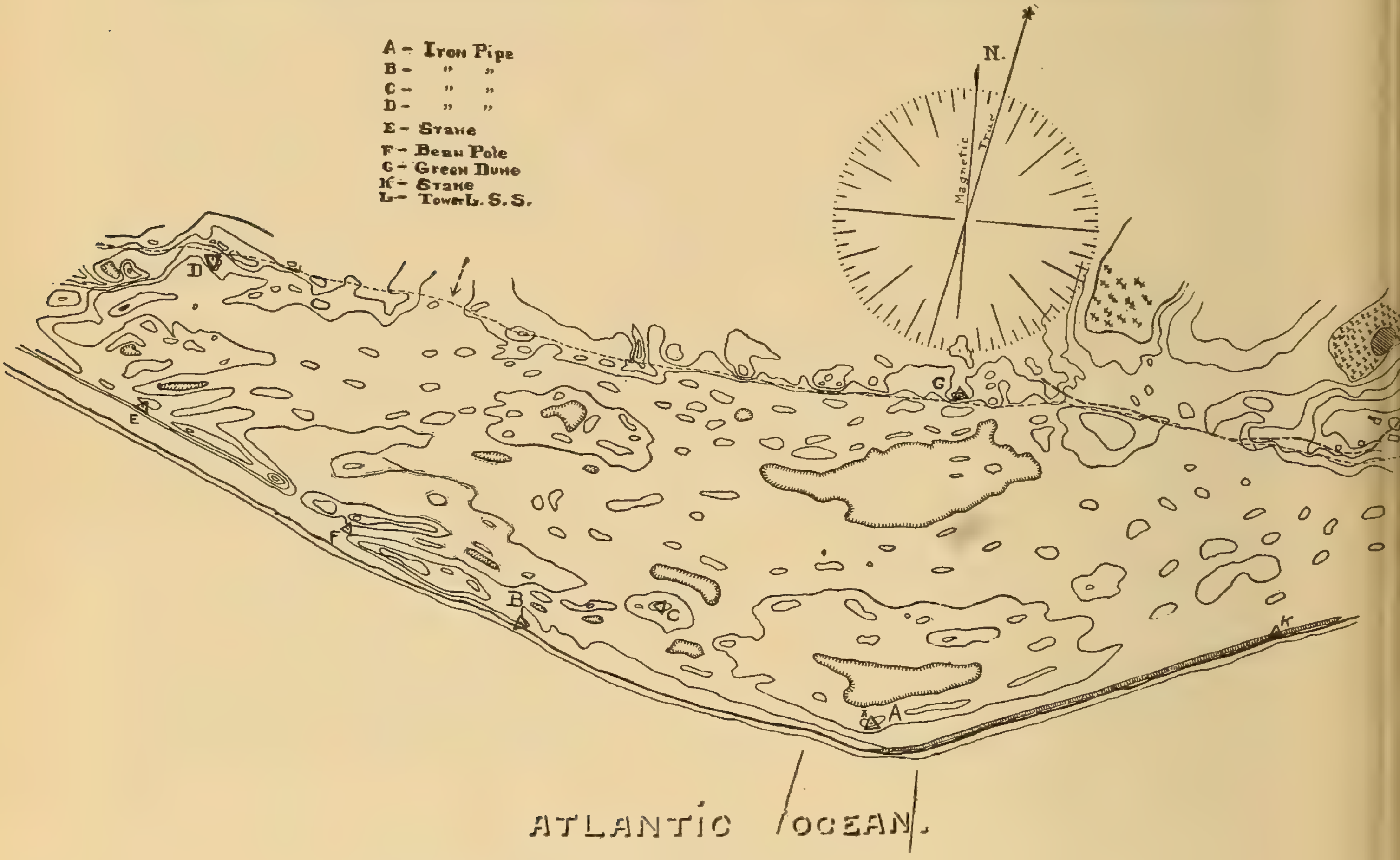

FIGURE 2.—*Miacomet Foreland, September, 1903. Scale, 1 : 10,000.*

To the east of the Life Saving station is a region where the island has been rapidly cut away in the past twenty years. The railroad in front of the old Surfside hotel was moved back several times before it was finally removed to the center of the island. Several hundred feet have been cut away to the east of the Life Saving station during the time that this foreland has been built southward some 1,200 feet in front of the old shoreline. This foreland is built at the point where the water breaks over what is known as Miacomet rip. Just why the rip should occur at this point and why the foreland should have been built out during the last forty years is a question of much interest in the study of the development of the island.

Before it is possible to attempt an explanation of the formation of Miacomet foreland it is necessary to gather as much information as possible as to the building of the foreland itself and as to the changes in position of the shoreline. During the summer of 1903 there have been several minor advances and retreats of the shoreline between the points *A* and *K*. At certain times the waves cut into the sand, leaving a well marked cliff and often two weeks later this cliff would have been replaced by the crescentic sand forms of aggradation.

From the accounts of old sea captains on the island it appears that some forty years ago it was possible to draw dories up on the sand at the foot of the Green dune (*G*). This would indicate that the 1,200 feet of sand had been built out within forty years. It is possible that there might have been some sand built as a foreland west of the point (*G*) in 1860.

The total length of this foreland along the shore is between 5,000 and 6,000 feet, and although at many places there are ridges of dunes which probably indicate former shorelines, there is no symmetrical series of such ridges, such as is shown in Dars foreland in Germany and the Canaveral foreland, Florida. The wind apparently shifts these dunes very considerably during the winter storms. It is probable that the shore ridges which were formed have been almost completely obliterated between the present shoreline and the shoreline extending from the life-saving station past the Green dune to station (*D*).

MADDAKET

Some 6 miles west of the Miacomet foreland is a region where there has been pronounced cutting back in the shoreline within the last few years. The Life Saving station at this point gives the measure of this cutting back from 1889 to 1903. The shoreline at this point has been cut back 250 feet from 1889 to 1903, a period of fourteen years. This is an average of about 18 feet a year for the last fourteen years. The record at this point has been pretty continuously kept, because the Life Saving station has had to be moved back as the sea cut in. From measurements made by the writer on the original plane-table sheets of the Coast Survey it appears that the shoreline retreated 173 meters (567 feet) from 1846 to 1887.

There appears to be a cutting back of the shoreline on the whole southwestern coast of Nantucket from the west end of Miacomet foreland to the extreme western extension of Smith point, and also on the southern portion of Tuckernuck island and Smith beach. This would show that this great stretch of shoreline is being cut back on the western side of Miacomet foreland the same way that on the eastern side there is another great region where the sea is actively cutting back. Miacomet foreland is an area of aggradation lying between two areas of retreating shoreline.

Two views are given taken from the top of the tower of the Life Saving station at Maddaket. These were taken on September 6, 1903. The first one is looking west toward Smith point and shows Tuckernuck in the distance (plate 51, figure 1). A planetable map of this area is given in figure 4. The second view is looking north from the Life Saving station and shows the northern extension of Hither creek (plate 51, figure 2). The southern end of Hither creek was shown on the first photograph. In the distance on the second photograph Eel point is seen, and between Eel point and the Maddaket houses in the foreground is Maddaket harbor. Hither creek, as seen in these photographs, is one of the many valleys which cross the southern portion of Nantucket and which will be discussed in a later paper. Many of these valleys now form ponds, as Long pond, Hummock pond, etcetera.

Origin of Valleys

There are four hypotheses for the method of formation of these valleys which the writer has considered in his study of the island. The first of these is that the valleys were formed before the ice covered this region. These valleys were, then, formed when the land stood higher than it does at present, and were later covered with a comparatively thin mantle of glacial waste, and then the land was depressed to its present position. The second is that the valleys were formed in an interglacial period. The third is that the valleys were formed during the time of the deposition of this glacial waste, and that they represent water channels when the ice stood at the head of the valley. The fourth is that the valleys were formed since the Glacial period.

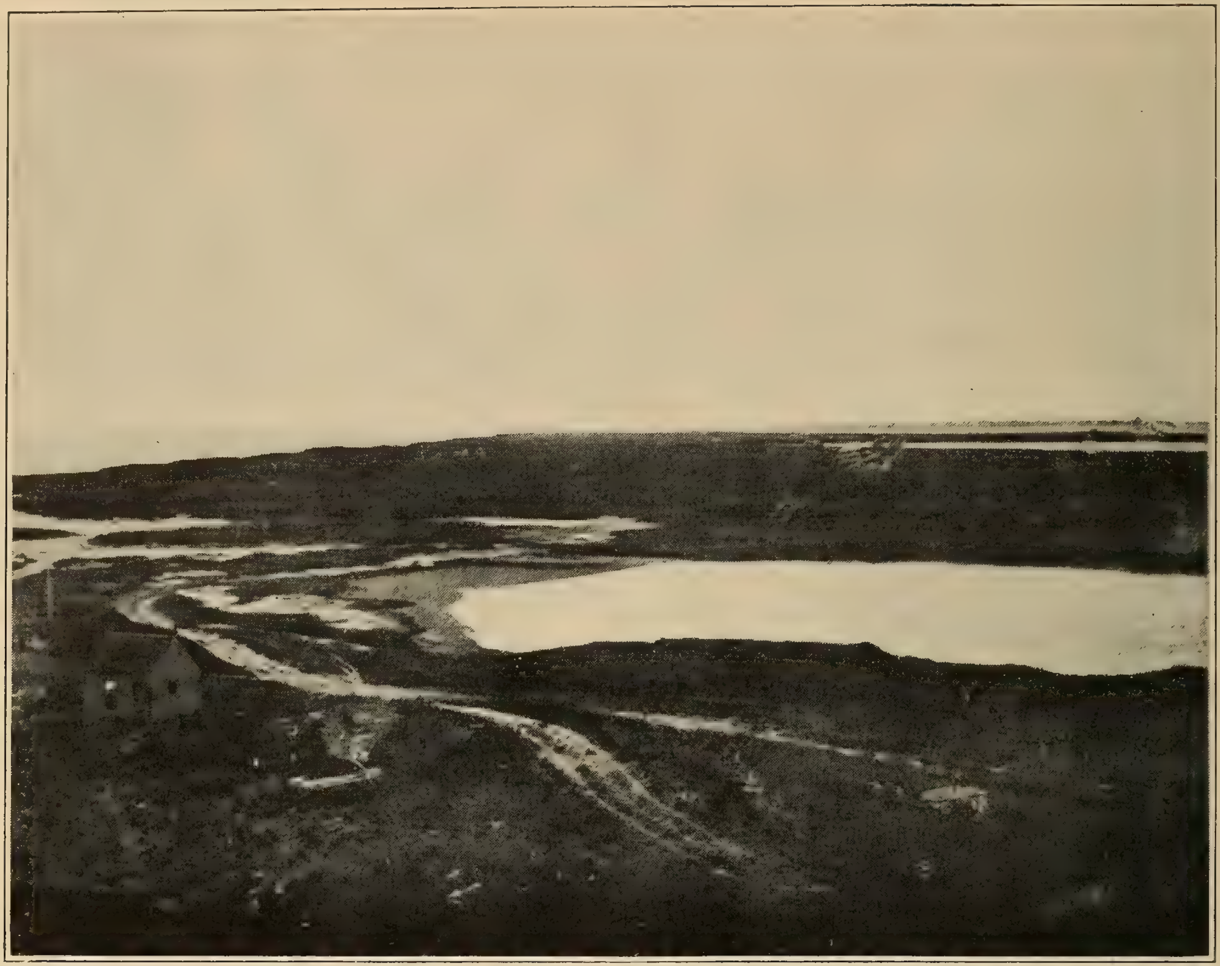

FIGURE 1.—SMITH POINT FROM TOWER OF MADDAKET LIFE SAVING STATION

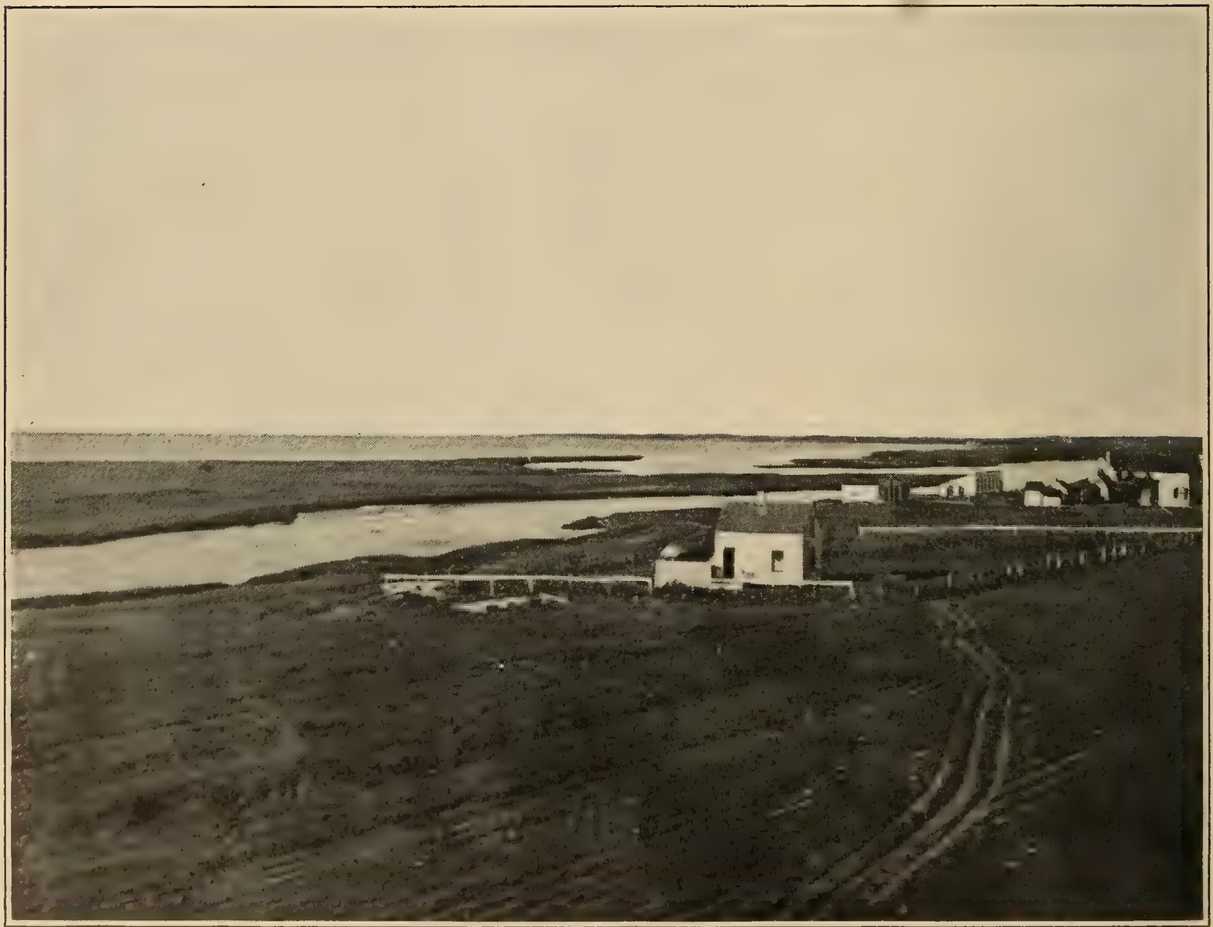

FIGURE 2.—HITHER CREEK AND MADDAKET HARBOR

SMITH POINT AND MADDAKET HARBOR

The writer has not finished his study of this problem sufficiently to come to a final conclusion. From the evidence thus far obtained it seems that the first hypothesis above mentioned is the most probable one.

SMITH POINT

Since the first white man came to Nantucket records show many changes in the form of the western tombolo, which attempts to form a connection between Nantucket island and Marthas Vineyard. At times the tombolo has been completed as far as Tuckernuck; at times it has been entirely south of Tuckernuck, as shown in the Mitchell map of 1838 (see figure 3). This map is here reproduced in outline, as it is the best map made before the first U. S. Coast and Geodetic Survey map. It will not be fully discussed in this paper, as reference to it will be made in a later paper when some of the old maps of the region are considered.

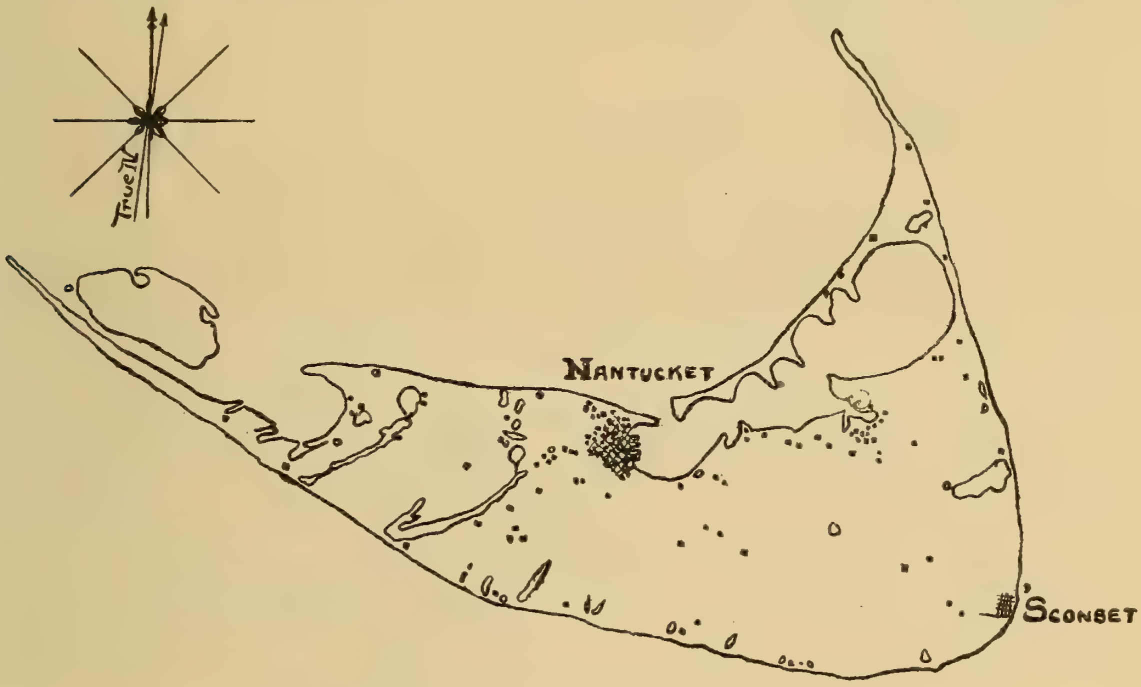

FIGURE 3.—*Map of Nantucket, by Wm. Mitchell, 1838.*

At present the tombolo is neither continuous to Tuckernuck, nor is it entirely south of Tuckernuck, as shown in the Mitchell map. There is now a channel across the tombolo east of Tuckernuck. It occurs just west of the point where the oldland of Nantucket proper ends, according to the interpretation of the writer. This opinion is based on the forms of the valleys which cross the island at this point, extending northeast and southwest. These valleys between the Maddaket Life Saving station and the end of Smith point were drowned at the beginning of the present cycle, and have now been cut back on the southwest side almost to their northern limit. Hither creek, Broad creek, Narrow creek, and Further creek, now opening into Maddaket harbor, represent valleys which were not quite drowned by the depression of the land at the beginning of the present cycle. It is a question how far these valleys extended to the southwest at the beginning of the present cycle. The writer hopes to make a study of this question at some future time, based on the records given on the old maps and from the general study of the rate of erosion of the island.

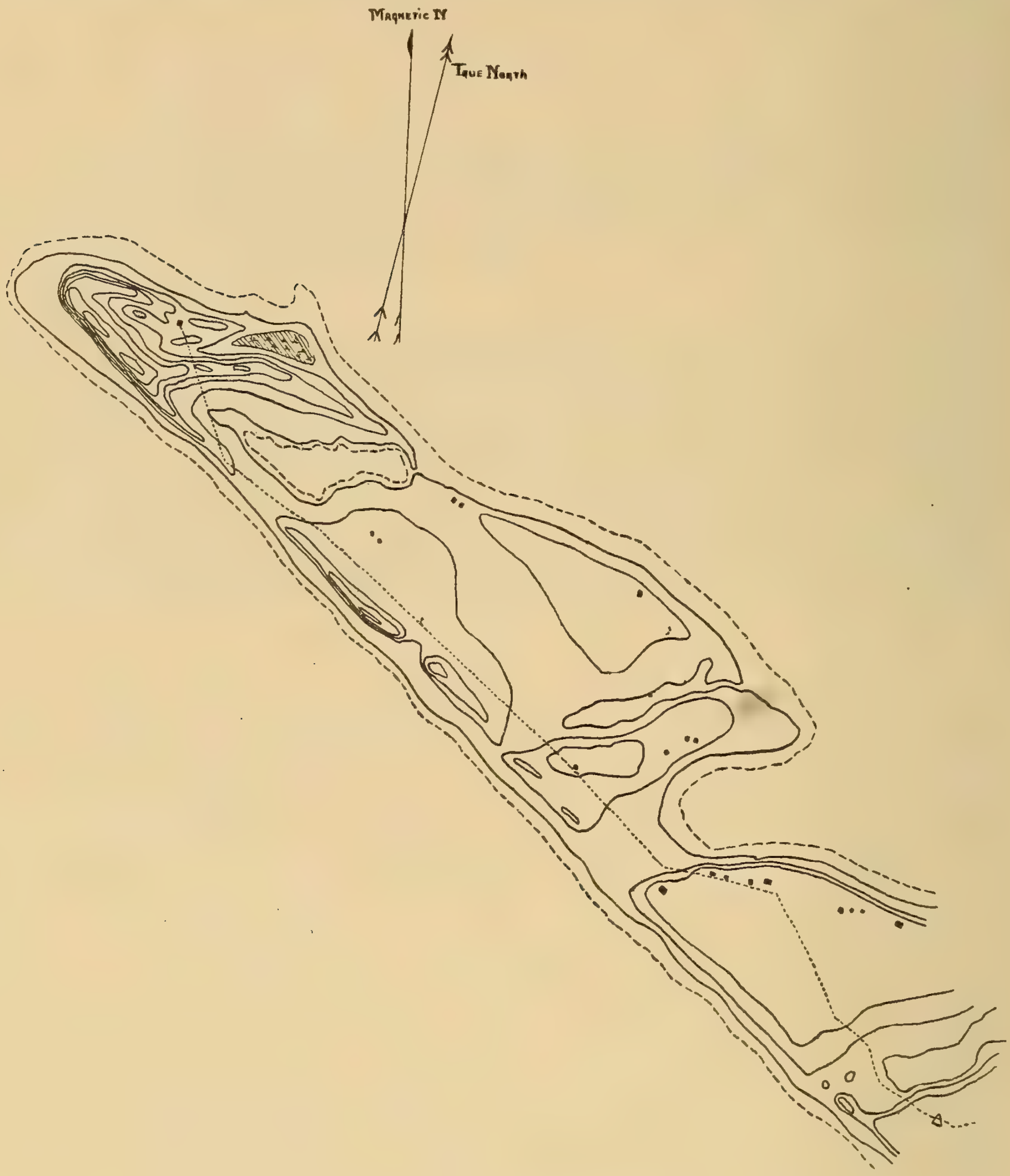

FIGURE 4.—*Smith Point, September, 1903. Scale, 1 : 25,000.*

In September, 1903, the writer made a planetable survey from the Maddaket Life Saving station to the end of the point. This map is here reproduced (figure 4). It is based on a traverse line with intersections to various buildings on the point. Along the southern shore there is a ridge of sand dunes, and on the western point beyond Further creek these dunes are built around on the northern side of the point. The contours are sketched at approximately 5-foot levels. The oldland on the point is nowhere more than 10 feet high west of the Life Saving station. The dunes are in places 20 and 25 feet above high water.

Inasmuch as the tombolo was never completed from Nantucket to Marthas Vineyard, a great deal of sand has been carried to the north of Tuckernuck by the currents. This sand has been built into the Tuckernuck, Muskeget, and other shoals which will be considered in a later paper. The many sand dunes in the large sand dune area of Eel point and the action along the northern shore of Nantucket west of the town will be discussed in a later paper. We will now proceed to consider the sand brought around to the north of the island and deposited near the town.

BRANT POINT

The sand carried along the northern part of Nantucket from the west has been built out into the foreland in front of the cliff forming Brant point. This point has been built out into the harbor, with its axis about at right angles to the general direction of the inflowing and outflowing tidal currents, and represents one of the tidal cuspate forelands which the writer has previously described.* The point extends about a mile to the east of the cliff. It appears to have been built as a bar extending to the east toward the lighthouse and then curving back toward the town. At first this must have inclosed a lagoon which has now been filled up into a marsh. There are traditions of sailing in behind this bar and anchoring in the area north of the Point Breeze hotel. The outline of this point was probably at first very similar to its present form. The point, however, has extended farther to the east, as is shown in the change of the position of the lighthouse. The old lighthouse, built in 1856, is now 600 feet back from the light built in 1900–1901. The last hundred feet of this distance has been built more rapidly than the first portion, as it has extended about 100 feet in the four years from 1898 to 1902.

It is a question of a good deal of interest to know exactly how these tidal cuspate forelands are formed, and the writer hopes to find, by a study of this point, some of the things which control and determine the growth of such points, which appear to grow directly into the main tidal current in any bay. It is for this reason that the writer proposed the scheme of eddies formed between the old land and the main in and out flowing currents. There are many recorded changes in the form of this point since the beginning of the plans for the improvement of the harbor by the building of the jetties, and during the last 25 years there have been many detailed studies of this region made by the engineers. A study of the changes which can be directly traced to the building of the jetties and the consequent increase of the tidal in and out flow will be very helpful in any discussion of the general method of the formation of these cuspate projections of sand into bays.

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*Shoreline topography, Proc. Am. Acad. Arts and Sci., vol. xxxiv, pp. 214–220.

One of these changes is due to the fact that the western jetty prevents the movement of the sand from the northern shore of the island out to the end of Brant point; consequently the sand is piled against the jetty on the west side at the bathing beach. From 1881 to 1897 the shoreline on the west side of the west jetty extended 250 feet farther northward along the jetty, and from 1897 to 1902 150 feet more. Thus in twenty years there was an extension at this place of 400 feet. Of course, sand has been blown over the jetty and carried along toward the end of Brant point, but the west jetty has prevented the free movement of sand along the northern side of the point. Half way between the western jetty and the end of Brant point the shoreline was cut back during these twenty-one years from 1881 to 1902 100 feet. This was due undoubtedly to the increased flow of the tidal currents in and out of the harbor between the two jetties.

NANTUCKET HARBOR

The point of greatest interest to most people in the study of the changes around Nantucket is the question as to how the movements of sand along the shore will affect the depth of water in the harbor, and what improvements must be made in order to keep the harbor from filling up, so that it can no longer be used as a port. The two jetties built from Brant point and Coatue were constructed to increase the depth of water across the bar at the mouth of the harbor. The jetties have never been completed, and it is decidedly a question how great the increase in the depth of channel across the bar would be if they were completed. The theory of such jetties as this is that the tidal in and out flow, being confined to the narrow channel, will scour out the sand and leave a channel in the runway. As long as the east jetty is uncompleted, it allows the water to go through the gaps, and thus the full strength of the in and out flowing currents is never attained.

The general conditions of the erosion of the island show that the sand is worn away from the exposed portions and deposited in the quieter waters on the landward side of the island. Great point, Smith point, Brant point, and Coatue all represent deposits built up by the sea out of the waste of other portions of the island. The harbor thus formed by Brant point and Coatue is a body of water much protected from the action of the waves and consequently of value to man. It is, however, a region of comparatively quiet water, and therefore a region where sand may be deposited more easily than in Vineyard sound. If sand is carried in by the tide, there is a tendency to raise the level of the sand flats in the harbor, when more sand is carried in by the rising tide than is carried out by the falling tide. Another source of filling is, of course, the sand brought in by the wind across Coatue. Except in the region of the jetties, no detailed studies have been made of the rate of filling of the harbor. It was supposed that the breaking through of the Haulover might effect a scouring out of the sand in the harbor by forming a tidal current from the head of the harbor to the opening between Brant point and Coatue. It was even proposed * to cut through the tombolo at the head of the harbor in order to increase the tidal scour at the mouth of the harbor. The results of the breaking through of the Haulover show that there was no appreciable effect at the mouth of the harbor from the opening between Coskata and Wauwinet. It was pointed out in the discussion of the forms of the tombolo since the break in the winter of 1896–'97 that the tombolo is really continuous below water, and that there never has been any channel across this tombolo deep enough to allow the water to have any force in scouring out the harbor.

The shoals between Coatue and the northern shore of the oldland are so near to the surface of the water that it would be impossible to get a current of any great erosive force to act south of Coatue without the expenditure of a very large sum of money.

COATUE

Coatue has been built from the oldland of Coskata island southwest toward the town of Nantucket, and forms a mass of sand 5 miles long, practically all of which must have come from the east side of Nantucket and traveled around Great point along Coskata beach. On the northwest side it has a smooth outline, showing that the dominant current is along the shore. On the southeast side there are six cuspate projections into the harbor, which probably indicate a small eddy current between each pair of points. On nearly all of these points there is at present a little pond, showing that the growth was probably that of a V-shaped bar inclosing a lagoon which has been more or less filled by sand. On the points of some of these forelands the lagoon is completely filled, and

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* Report of the Chief of Engineers, U. S. War Department, 1880, p. 431.

it is only by the form of the dunes as seen at present that the former presence of a lagoon is inferred. West of Coskata island there are a number of ridges showing the progressive stages of growth from the east to the west. These, however, do not extend along Coatue very far from Coskata. It would appear, therefore, that the growth of Coatue was gradually to the southwest, as the sand was supplied around Great point, the currents carrying it a little farther each year, and that each of the six points on the southeast side of Coatue projecting into the harbor was built by the eddy currents as the main mass of Coatue grew to the southwest. If this hypothesis of growth be a true one, Wyers point would be the earliest built and First point on the end of Coatue the last one built.

The filling of the lagoons would also indicate this to be the case, as no one would expect the same amount on the last formed points as on those first formed. First, Second, and Third points show the lagoon more prominently than Five-fingered point, Bass point, and Wyers point. The sand dunes are also higher on Wyers point than Second point.

From a theoretical point of view, a study of Coatue is of a good deal of importance, and it is proposed to watch the future changes as carefully as possible, and to look for any evidences of past changes as shown in deposits already built. Since the opening of the Haulover there has been a deposit built on the southwest side of Wyers point, indicating a movement along the shore from Coskata. This was carefully measured in the summer of 1903 for future comparison.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PROCEEDINGS OF THE SIXTEENTH ANNUAL MEETING, HELD AT SAINT LOUIS, MISSOURI, DECEMBER 30 AND 31, 1903, AND JANUARY 1, 1904, INCLUDING PROCEEDINGS OF THE FIFTH ANNUAL MEETING OF THE CORDILLERAN SECTION, HELD AT SAN FRANCISCO, JANUARY 1 AND 2, 1904.

HERMAN LE ROY FAIRCHILD, *Secretary*

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Session of Wednesday, December 30

The Society was called to order by the President, S. F. Emmons, at 9.30 o'clock a m, in room 210 of the Central High School, where all the sessions of the meeting were held except the evening session of this day.

On account of the absence of Professor J. A. Holmes, Chief of the Department of Mines and Metallurgy, Universal Exposition, who was expected to welcome the Society, no addresses were made.

The report of the Council was called for and was presented by the Secretary, in print, as follows:

REPORT OF THE COUNCIL

To the Geological Society of America,
in Sixteenth Annual Meeting Assembled:

The stated winter meeting of the Council was held at Washington with the meeting of the Society. In the absence of a summer meeting of the

Society no summer Council meeting was held, as no imperative business was waiting and the affairs of the Society continue in excellent condition. The following reports of the officers give the administrative details for the fifteenth year in the life of the Society:

SECRETARY'S REPORT

To the Council of the Geological Society of America :

Meetings.—The record of the Washington meeting, 1902, will be found in the closing brochure of volume 14 of the Bulletin. As announced at Washington, and subsequently by circular letter, the summer meeting was suspended.

Membership.—Since the last report three Fellows have died—Wilbur C. Knight, J. P. Lesley, and Peter Neff. The five Fellows elected at the last meeting all qualified. Three Fellows have been dropped from the rolls for non-payment of dues, and the present enrollment is 254, two less than last year. Eleven nominations are now before the Society and several are awaiting action by the Council.

Bulletin Sales.—Receipts from sale of the Bulletin during the past year appear in the following table:

Receipts from Sale of Bulletin, December 1, 1902, to December 1, 1903

	Complete volumes.			Brochures.			Grand total.
	Public.	Fellows.	Total.	Public.	Fellows.	Total.	
Volume 1..	$10 00	$13 50	$23 50	$2 25	$0 15	$2 40	$25 90
Volume 2..	10 00	13 50	23 50	3 65	35	4 00	27 50
Volume 3..	10 00	12 00	22 00	4 05	2 55	6 60	28 60
Volume 4..	10 00	10 50	20 50	1 18	....	1 18	21 68
Volume 5..	10 00	12 00	22 00	2 50	25	2 75	24 75
Volume 6..	10 00	12 00	22 00	....	45	45	22 45
Volume 7..	10 00	8 00	18 00	1 20	90	2 10	20 10
Volume 8..	10 00	12 00	22 00	2 40	....	2 40	24 40
Volume 9..	15 00	12 00	27 00	20	65	85	27 85
Volume 10..	20 00	8 00	28 00	2 50	....	2 50	30 50
Volume 11..	25 00	13 50	38 50	1 70	2 90	4 60	43 10
Volume 12..	20 00	8 00	28 00	4 60	4 75	9 35	37 35
Volume 13..	280 00	4 50	284 50	6 80	1 90	8 70	293 20
Volume 14..	130 00	....	130 00	....	....	....	130 00
Volume 5..	30 00	....	30 00	....	....	....	30 00
	$600 00	$139 50	$739 50	$33 03	$14 85	$47 88	$787 38
Index......	7 25	6 75	....	......	....	....	14 00
	$607 25	$146 25	$753 50	$33 03	$14 85	$47 88	$801 38

Receipts for the fiscal year	$801 38
Previous receipts, to November 30, 1902	6,775 70
Total receipts to date	$7,577 08
Charged and uncollected	15 00
Total Bulletin sales to date	$7,592 08

The bills which have not yet been sent to regular subscribers for volume 14 will add at least $250 to the amount of sales.

During the 13 years that the Bulletin has been on sale the amount of sales has averaged about $583 yearly. The subscription list is slowly growing by addition of libraries, and the average of sales for the last three years is $778.

Distribution of Bulletin.—At this date 368 pages of volume 14 have been mailed. The irregular distribution of the Bulletin during the past year has been as follows: Complete volumes sold to the public, 37; to Fellows, 24; 17 brochures have been sent to fill deficiencies; 41 have been sold to the public and 37 to Fellows. One copy of volume 13 has been donated and three bound for use of the officers and the library.

Exchanges.—The list of exchanges includes 88 addresses, one more than last year. The list appears at the close of each Bulletin volume.

Expenses.—The following table gives the cost of administration and Bulletin distribution from the Secretary's office during the past year.

EXPENDITURE OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDING NOVEMBER 30, 1903

Account of Administration

Postage and telegrams	$25 75	
Expressage	1 80	
Printing (including stationery)	101 25	
Meetings (not included in printing)	30 80	
Total		$159 60

Account of Bulletin

Postage	$112 25	
Expressage and freight	57 29	
Wrapping material (envelopes, &c.)	33 08	
Addressing machine ("Addressograph")	59 81	
Binding three copies volume 13	3 00	
Purchase of brochures to fill deficiencies	8 00	
Collection of checks	3 10	
Total		276 53
Total expenses for the year		$436 13

Respectfully submitted.

H. L. FAIRCHILD,
Secretary.

ROCHESTER, N. Y., *December 20, 1903.*

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the year ending December 1, 1903, along with other data of general interest.

Three Fellows have been dropped from the roll for non-payment of dues. Eight remain delinquent for two years, while twenty-eight are delinquent for this year.

Five Fellows, L. C. Glenn, G. P. Grimsley, C. K. Leith, W. G. Miller, and C. H. Warren, have enrolled for life by the payment of the $100 fee, thus increasing the total number of life commutations to sixty-three.

The investment committee appointed at the last session of the Council has purchased during the year twenty shares ($2,000) of the capital stock of the Ontario Apartment House Company of Washington, D. C., so that the total par value of the stocks and bonds now held on account of the publication fund exactly equals the sum ($6,300) received from life commutations. The Society will realize 4 per cent interest on the Ontario Apartment House Company stock until the large building under construction is ready for occupancy, and thereafter not less than 6 per cent annual dividends, according to the results of all previous investments of this nature in Washington real estate. It should be added that the Treasurer is solely responsible for this investment.

The interest received from all sources amounts to $396.17 against $387.94 for last year, but this year's total should really be increased by a sum of more than fifty dollars, accrued since March on the Ontario Apartment House Company stock, which is not payable until January 1, 1904.

The securities now owned by the Society (all of which are deposited in the fire and burglar proof vaults of the Bank of the Monongahela Valley at Morgantown, West Virginia) are as follows:

Account of Publication Fund

April 1, 1891, 1 Tioga Township, Kansas, 7 per cent bond, cost, $1,140.26	$1,000
March 17 and 25, 1898, two Texas Pacific Railroad first mortgage 5 per cent bonds, cost, $1,976.25 *	2,000
February 6, 1901, 10 shares of the capital stock of the Iowa Apartment House Company, Washington, D. C.	1,000
April 1, 1903, 20 shares of the capital stock of the Ontario Apartment House Company, cost, $2,000	2,000
May 5 and September 27, 1895, 3 first mortgage 6 per cent bonds of the Kingwood, Tunnelton and Fairchance railroad, cost, $304	300
Total cost, $6,420.51; total par value	$6,300

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* The Texas Pacific bonds are quoted at 115 on the New York exchange.

Statement of Receipts and Expenditures

RECEIPTS.			
Balance in treasury November 30, 1902			$5,103 09
Fellowship fees 1900 (1)	$10 00		
" " 1901 (4)	40 00		
" " 1902 (14)	140 00		
" " 1903 (154)	1,540 00		
" " 1904 (1)	10 00		
		$1,740 00	
Initiation fees (5)		50 00	
Life commutations (5)		500 00	
Interest on investments:			
Tioga Township, Kansas, bonds	$70 00		
Iowa Apartment House Co. stock	60 00		
Texas and Pacific Railroad bonds	100 00		
Tunnelton, Kingwood and Fairchance Railroad bonds	18 00		
Interest on deposits with Security Trust Co	148 17		
		396 17	
Sales of publications		801 38	
			3,487 55
Total amount of receipts (carried forward)			$8,590 64

Amount of receipts brought forward			$8,590 64
EXPENDITURES.			
Secretary's office:			
Administration	$159 60		
Bulletin	276 53		
Allowance (traveling and clerical expenses)	500 00		
		$936 13	
Treasurer's office:			
Postage		15 00	
Librarian's office		9 75	
Photographic account		13 00	
			$973 88
Publication of Bulletin:			
Printing		$1,380 82	
Engraving		944 15	
Bibliography, etc.		10 00	
Editor's allowance, personal and office expenses		250 00	
			2,584 97
Investments			2,000 00
Total expenditures			5,558 85
Balance in treasury December 1, 1903			$3,031 79

The general financial condition of the Society, as shown by the receipts and disbursements for the past year, is exhibited in the preceding tabular statement.

Respectfully submitted.

I. C. White,
Treasurer.

Morgantown, W. Va.,
December 5, 1903.

Editor's Report

To the Council of the Geological Society of America:

At this writing 494 pages of volume 14 have been issued. This completes all papers and leaves only the Proceedings of the Washington meeting to be disposed of. The "copy" of this brochure was placed in the printer's hands before all of the individual papers were in type, but causes which prevented the early completion of volume 13 have operated with the same effect this year. By reason of its peculiar character-the publication of the Proceedings of the winter meeting is at best a slow operation, and if individual papers can not be disposed of before the end of October it is practically impossible to close the volume before the next winter meeting is held. All of this brochure is now in type, but it will not be ready for distribution in time for the Saint Louis meeting.

Volume 14 has 65 half-tone plates and 43 line drawings, making it one of the most attractively illustrated volumes ever issued by the Society, whose generosity in the matter of illustrations seems to be heartily appreciated by the Fellows.

The cost of volume 14 is given below in comparison with that of volumes 11, 12 and 13 and the average cost of the first ten volumes:

	Average. Vols. 1–10.	Vol. 11.	Vol. 12.	Vol. 13.	Vol. 14.
	pp. 544. pls. 26.	pp. 651. pls. 58.	pp. 538. pls. 45.	pp. 583. pls. 58.	pp. 609. pls. 65.
Letter-press	$1,465 14	$1,815 56	$1,445 73	$1,647 12	$1,657 50
Illustrations	200 40	373 68	414 80	477 27	431 21
	$1,665 54	$2,189 24	$1,860 53	$2,124 39	$2,088 71
Average per page	$3 23	$3 36	$3 45	$3 64	$3 43

The following is a reasonably correct analysis of the contents of volumes 7 to 14, inclusive:

Divisions.	*Vol. 7, Pages.*	*Vol. 8, Pages.*	*Vol. 9, Pages.*	*Vol. 10, Pages.*	*Vol. 11, Pages.*	*Vol. 12, Pages.*	*Vol. 13, Pages.*	*Vol. 14, Pages.*
Areal geology	38	34	2	35	65	199	125	48
Dynamic geology	3	24	85	24	110	23	17	47
Economic geology	4	14	16	28	7	5	4	1
Glacial geology	5	98	138	96	21	55	13	48
Historical	..	..	..	16	46	..	24	1
Memoirs	28	8	12	27	60	2	32	14
Official matter	56	69	54	72	59	58	153	68
Paleontology	123	58	64	68	188	5	42	22
Petrology	40	43	44	59	54	24	28	183
Pysiographic geology	53	5	..	37	10	53	24	59
Relation of geology to pedagogy	12	..	..	..	..	..	..	..
Rock decomposition	74	26	17	9	..	16	..	..
Stratigraphic geology	21	67	28	62	31	98	116	118
Terminology	1	..	..	1	..	..	5	..
Total	558	446	460	534	651	538	583	609

Respectfully submitted.

JOSEPH STANLEY-BROWN,
Editor.

NEW YORK, *December 15, 1903.*

LIBRARIAN'S REPORT

To the Council of the Geological Society of America:

The contributions to the Library received during the past year have been duly received, acknowledged, and catalogued, and the binding of the accessions has kept pace with their receipt. The list of additions to July 1, 1903, has been transmitted to the Secretary for inclusion in volume 14 of the Bulletin.

In several successive reports attention has been called to the fact that the Fellows make no use of the Library, with the exception of those located in Cleveland, and annual repetition of the statement would seem both useless and wearisome. A glance at the list of exchanges which annually appears in the list of accessions to the Library will enable any one to judge of what constitutes the bulk of the Library, and for the most part the files of these exchanges are complete from 1890 to date. Your Librarian would be glad to do anything in his power to facilitate use of the Library by the Society at large and glad of any suggestions from the Council as to methods of accomplishing this, but hardly feels justified in taking any personal initiative in the matter.

The expenses of the office for the past 12 months are as follows:

To express charges on "exchanges"	$2 05
300 international postal cards	6 00
printing of same	75
postage	95
	$9 75

Respectfully submitted.

H. P. Cushing,
Librarian.

Cleveland, Ohio, *December 15, 1903.*

On motion of the Secretary, it was voted to defer consideration of the Council report until the following day.

As the Auditing Committee to examine the accounts of the Treasurer, the Society elected E. O. Hovey and G. K. Gilbert.

ELECTION OF OFFICERS

The result of the balloting for officers for 1904, as canvassed by the Council, was announced by the President, and the officers were declared elected as follows:

President:

John C. Branner, Stanford University, Cal.

First Vice-President:

H. S. Williams, New Haven, Conn.

Second Vice-President:

Samuel Calvin, Iowa City, Iowa.

Secretary:

H. L. Fairchild, Rochester, N. Y.

Treasurer:

I. C. White, Morgantown, W. Va.

Editor:

J. Stanley-Brown, Washington, D. C.

Librarian:

H. P. Cushing, Cleveland, Ohio.

Councillors:

John M. Clarke, Albany, N. Y.
George P. Merrill, Washington, D. C.

ELECTION OF FELLOWS

The Secretary announced that the candidates for fellowship had received a nearly unanimous vote of the ballots sent, and that Fellows were elected as follows:

ARTHUR BIBBINS, Ph. B., Baltimore, Md. Instructor in Geology, Woman's College.

GILBERT DENNISON HARRIS, Ph. B., Ithaca, N. Y. Assistant Professor of Paleontology and Stratigraphic Geology, Cornell University; Geologist in charge of the Geological Survey of Louisiana.

RICHARD R. HICE, B. S., Beaver, Pa. Manufacturer of brick and terra-cotta.

ERNEST HOWE, Ph. D., Washington, D. C. Assistant Geologist, U. S. Geological Survey.

WILLIS THOMAS LEE, Ph. B., M. S., Phœnix, Ariz. Assistant Geologist, U. S. Geological Survey.

WILLIAM DILLER MATTHEW, Ph. D., New York City. Associate Curator in Vertebrate Paleontology, American Museum of Natural History.

THOMAS LEONARD WALKER, Ph. D., Toronto, Canada. Professor of Mineralogy and Petrography, University of Toronto.

FRED BOUGHTON WEEKS, Washington, D. C. Assistant Geologist, U. S. Geological Survey.

SAMUEL WEIDMAN, Ph. D., Madison, Wis. Geologist, Wisconsin Geological and Natural History Survey.

EDWARD O. ULRICH, D. Sc., Washington, D. C. Assistant Geologist, U. S. Geological Survey.

FREDERIC EUGENE WRIGHT, Ph. D., Houghton, Mich. Assistant State Geologist and Instructor in Petrography, Michigan College of Mines.

No new business was presented. The President called for the necrology, and the following memoirs of deceased Fellows were presented. In the absence of the author the first memoir was read by I. C. White:

MEMOIR OF J. PETER LESLEY

BY JOHN J. STEVENSON

J. Peter Lesley, born in Philadelphia September 17, 1819, died in Milton, Massachusetts, June 1, 1903.

His youth was spent in Philadelphia, and in 1838 he was graduated at the University of Pennsylvania. Professor Henry D. Rogers at once appointed him an aid on the Pennsylvania Geological Survey and in the following spring assigned him to assist Mr Henderson in the anthracite area; but within a few weeks Mr Henderson was transferred to another district, and Lesley was left alone to collect systematic information from the collieries and to instruct himself in field work. In 1840 he made a topographic and geologic sketch map of the complicated Siluro-Devonian area between Harrisburg and the New York line, and afterward, as assistant to James T. Hodge, studied the Carboniferous of Somerset and

Yours truly
J. P. Lesley

adjacent counties, confining his attention to the coal beds, while Mr Hodge studied the iron ores. During this season he identified with the Pittsburg the great coal bed at Salisbury, in Somerset county. In 1841, the last year of the survey, he made a reconnaissance of the northern and northwestern part of the state, studying the fourth and fifth bituminous coal basins as far south as Kittanning, on the Allegheny river, and rounded out the year's work by a new study of the anthracite region, completing the map left unfinished by Whelpley when he resigned, in 1839. During 1840 and 1841 Lesley worked out the detailed and generalized sections of the lower productive and lower barren measures now known as the Allegheny and Conemaugh formations—all this before reaching his twenty-second birthday. His studies were made when much of the country was still a forest-covered wilderness, when roads were few, when aneroid barometers and pocket levels were unknown, and ordinary intervals were measured by estimate. His work in Somerset and the adjacent area was mere reconnaissance, yet his work, closely reviewed by geologists of the second survey, needed little more of correction than did that of certainly one member of the second survey made in parts of that region thirty-five years later and under more favorable conditions. The skill with which Lesley and his youthful colleagues unraveled complicated structure was little short of divination.

The survey ended somewhat abruptly with the season of 1841—the geologists were scattered—but Professor Rogers began to prepare his final report, hoping that the state might be induced to publish it. Lesley had entered Princeton Theological Seminary to "indulge in a course of theology," but his skill as topographer and draughtsman, his knowledge of structure in all parts of the state, above all, his integrity and loyalty, made him indispensable to Rogers, so that all of the time, not imperatively required for study, was employed in preparing maps and diagrams for the final report. At that time the only map of the state was so inaccurate as to be undeserving of its name. There were numerous county maps, some of which had been colored and in some measure corrected by members of the corps; Lesley had made many corrections wherever he went, and there were a few detached areas which had been surveyed carefully. Such material as existed was given to Lesley that he might construct the map. He has described the process, how the county lines were forced into adjustment from both ends of the state to the Susquehanna river, where the total error accumulated; this gross error was distributed backward east and west over the whole state "so that the fundamental skeleton of the map was 'tempered' like a piano forte, being erroneous throughout, but with the local errors reduced to a minimum." On this county line scheme he plotted the topography, "good, bad, and indifferent," and laid down the foundation colors. This done, he constructed thirteen cross-sections and drew to a scale several hundreds of local sections, diagrams, and sketches, the whole work occupying eighteen months of 1842 and 1843.

Having completed his theological course, Lesley was licensed to preach by the Presbytery of Philadelphia in 1844 and at once went to Europe, where he made a pedestrian tour through France and Germany, which he closed with a brief course of study at the University of Halle. Returning to America, he undertook colportage work in northern Pennsylvania for the American Tract Society, which he pursued with characteristic energy and success for two years. In December, 1847, Professor Rogers asked him to come to Boston, where for five months he was busy in preparing duplicate copies of the geological map and sections, which were to be placed in the state capitol at Harrisburg. While in Boston he received and accepted a call to the pastorate of the Congregational church at Milton, Massachusetts, where he remained until 1851. In this interval his views respecting some theological matters developed along lines not wholly acceptable to his ministerial associates, so that at the end of four years he resigned his charge, abandoned the ministry, and returned to Philadelphia, where he began to practice as consulting geologist. At once his services were sought again by Professor Rogers, who had obtained an appropriation for preparation of the final report, and for more than a year he was engaged upon the revision work.

Thenceforward for forty years his labor was incessant. He was recognized at once as the most competent of geological experts, and his time was fully retained. Yet from 1855 to 1859 he was secretary of the American Iron Association, for which he published in 1859 a huge volume, the "American Iron Manufacturers' Guide," a remarkable compendium of theory, practice, and statistics, which even now is of much value. From 1858 to 1885 he was secretary and librarian of the American Philosophical Society, rarely absent from its meetings and seldom failing to present a paper or to take part in the discussions. He made elaborate surveys of the Cape Breton coal field, of the Pennsylvania coke region, of the Broad Top area, of the Cumberland Valley iron ores, and of many other areas outside of his own state, and besides found abundance of time in which to learn several languages and to prosecute special studies in several departments of literature and philosophy. In 1872 he was made professor of geology and dean of the faculty of science in the University of Pennsylvania, but in 1878, owing to the pressure of other duties, he resigned the deanship. The Second Geological Survey of Pennsylvania was authorized in 1874, and he was placed in charge of the work, which he conducted until compelled by failing health to relinquish it, in 1895.

He was an original member of the National Academy of Sciences and was president of the American Association for Advancement of Science in 1884.

Professor Lesley's first important publication was the little volume entitled "Coal and its Topography," which appeared in 1856. Professor Rogers, after completing the field work necessary for preparation of his final report, had gone to Edinburgh to supervise the publication. By some means, early in 1856, Lesley learned that in this report the geologists who had done the field work, who had solved the problems of geology and topography, and had made some of the most important generalizations were to be ignored. The information was not quite exact, for when the report appeared a list of those who had been connected with the survey was given in the preface, so that one may not say that they were wholly ignored. Spurred by indignation, Lesley wrote the book to preserve for his colleagues at least a share of the credit which was their due. The work was done amid the cares of a great practice, much of it at night after fatiguing days at the office, yet in six weeks the manuscript was ready for the press. The book served the purpose; as it were, incidentally it defined the area and work of the several geologists, but it was more important than its author intended or supposed. There one finds the first systematic grouping of the Appalachian coal beds and the first attempt at genuine correlation with beds elsewhere. The general description of coal and coal beds, as well as of the condition of their occurrence, is still unexcelled, while the discussion of topography in the second part remains, even in the light of present knowledge, one of the most brilliant contributions to physical geography, anticipating, not in germ, but in full, much of what is termed the modern method.

A work of wholly different type is "Man's Origin and Destiny," the Lowell lectures for 1865–1866, which appeared in 1868. The subjects range from signification of the sciences through the antiquity, dignity, and social life of mankind to origin of architecture growth of the alphabet, types of religious worship, and, finally, to what he terms arkite symbolism. When one considers that these lectures were prepared away from home and without access to books, he must admire the industry which had gathered a so great mass of knowledge, the memory which could retain it, and the mind so systematic as to make it readily available. Much of the work, it is true, is no longer important, as many of the conclusions were based on current, but erroneous, interpretation of oriental documents, yet students familiar with the results of recent investigations can not fail to find much of value in the author's method. If some of the parallelisms appear absurd today, the reader should remember that they were legitimate according to the philological methods of forty years ago; it is quite possible that the parallelisms of today may appear equally absurd forty years hence. In any event one can not fail to recognize the skill and ingenuity displayed in the chapters on the alphabet and on arkite symbolism, in which a great superstructure rises on the words " bar " and " ark," this petty foundation seeming to expand as the work proceeds, until at length the whole superstructure appears to rest secure.

Professor Lesley's great work was performed as director of the Second Geological Survey of Pennsylvania. He was head rather than director. An assistant once appointed was left practically to his own devices; but there was something about the personality of the director that impelled each one to do faithful work, that made the unambitious man ambitious. When the second survey was authorized the conditions were much the same as when Rogers undertook the first survey. There were few trained geologists in the country, and most of those were connected with one or the other of the United States surveys. Professor Lesley had to begin with young men, of whom only three or four had had any experience whatever in field work. He dealt with them generously, considerately, and, remembering his own early work, held them in all confidence. At times, indeed, he forgot that they were not men of broad experience, and his criticisms were none too mild. At others, unstrung by continuous application, he misunderstood the text of a report or misinterpreted a letter, and relieved himself in a communication which was a model of terseness and clearness, and which usually provoked a rejoinder approximately clear and terse. But such misunderstandings were of brief duration; breaches were healed quickly by his whole-souled reparation, and temporary ruptures served in the end to knit him and the assistants more closely than before.

Yet in one direction Professor Lesley never could forget during the early years of the survey that his assistants were inexperienced, and his constant anxiety was to prevent that lack of experience from doing injury either to them or to the state. In those days the time of proofreading was often a time of perplexity to authors of reports, who frequently discovered parenthetical comments or argumentative foot-notes which were not in every case edifying. Lesley had reconnoitered most of the state during the first survey, and in after years he had made detailed studies in many disconnected portions, especially in the coal, oil, and iron areas, so that he had well defined opinions respecting almost all localities. When assistants arrived at conclusions contrary to his own he felt compelled to present what he believed to be the more accurate conceptions.

The results of the work in each district were summarized in prefaces to the several reports. The necessity for such summaries increased with the number of volumes, for the districts were studied independently, and no report was bound closely to those by other observers in neighboring districts. These prefaces were steps toward a final report, enabling students to utilize quickly the work done in an extended area showing the same general phenomena. The labor involved in preparing them was very great; the manuscript of each report was read with the utmost care; the accompanying maps were studied with equal care, and not a few of them were redrawn by Lesley himself, who prepared also many of the elaborate indices—all this, that he make himself thoroughly familiar with the details.

How well he succeeded is shown by the final report, which, unfortunately, he could not complete. He had finished the story to the end of the Lower Carboniferous, when his health gave way, and the rest of the work was prepared by others. In this report he summarized every volume; he gives full credit to each member of his staff, while important phenomena, observed by the assistants, receive full discussion from the standpoints of his broad reading and his own field work. There is no attempt to evade anything, no inclination to undervalue the work of those disagreeing with him; on the contrary, there is a frank presentation of opposing views and frequently a retraction of opinions long held very dear by him. The more than one hundred and twenty volumes of survey reports are his monument.

Professor Lesley's power of endurance was almost equal to his industry; indeed, for many years his capacity for work seemed to be unlimited; but in the later sixties, during the early expansion of the oil industry of Pennsylvania, the limit was reached and his health collapsed. Recovery was very slow, but complete; thereafter he lived strictly by rule. During the years 1874 to 1891, the active years of the second survey, he closed his office promptly at 4 o'clock, giving six hours of concentrated labor daily. But the preparation of the final report required haste, and his day knew no measure, with the result that in 1893 his life as a student ended without warning. He was able to supervise matters for almost two years longer, and then, the work having been completed, he retired to Milton, Massachusetts, where the remaining years of his life were spent in comfort amid scenes which had always been dear to him.

Throughout Professor Lesley sought only to do to others as he would have them do to him. If at times in a discussion he aimed directly at the weak places in his adversary's armor and drove his weapon home with his might, all knew that no rancor accompanied the thrust. He was but a champion defending the right, and he always recognized that his adversary was equally honest, though of course on the wrong side.

He knew nothing of envy. The world with its rewards was large enough for him and all others besides; but he seemed to feel it a sacred duty to protect those who had gone before, to prevent others from ignoring them, and to secure for them all honor for their work, even though it were imperfect. Ever ready to defend the rights of others, he was indifferent to his own. If another appropriated his work, he appeared to feel no irritation; rather was he inclined to regard the confiscation as evidence that his work had proved to be a genuine contribution to knowledge. He loved to remember the good and to forget the ill done by others with whom he had been in relation. On one occasion the writer endeavored to dissuade him from a contemplated action, assuring him that the person to be benefited was more than unfriendly. The answer came sharply, "Friend once, friend always; that is my motto. If you wish to have a happy old age, you will do well to take it for your own." This was no burst of rhetoric; it was the explanation of his life.

Professor Lesley was the last of the old geologists, the only link binding us to the men of the early years, 1837 to 1841. His life was proof that the tradition respecting the character and ability of those men is true. He was a cheery, winsome companion, an effectionate husband and father, loved and revered in his household, honored by his friends. As was fitting, he passed away without suffering, literally crossing the threshold in sleep. In 1849 he married Susan Inches, daughter of the Honorable Joseph Lyman, of Northampton, Massachusetts, who, with two daughters, survives him.

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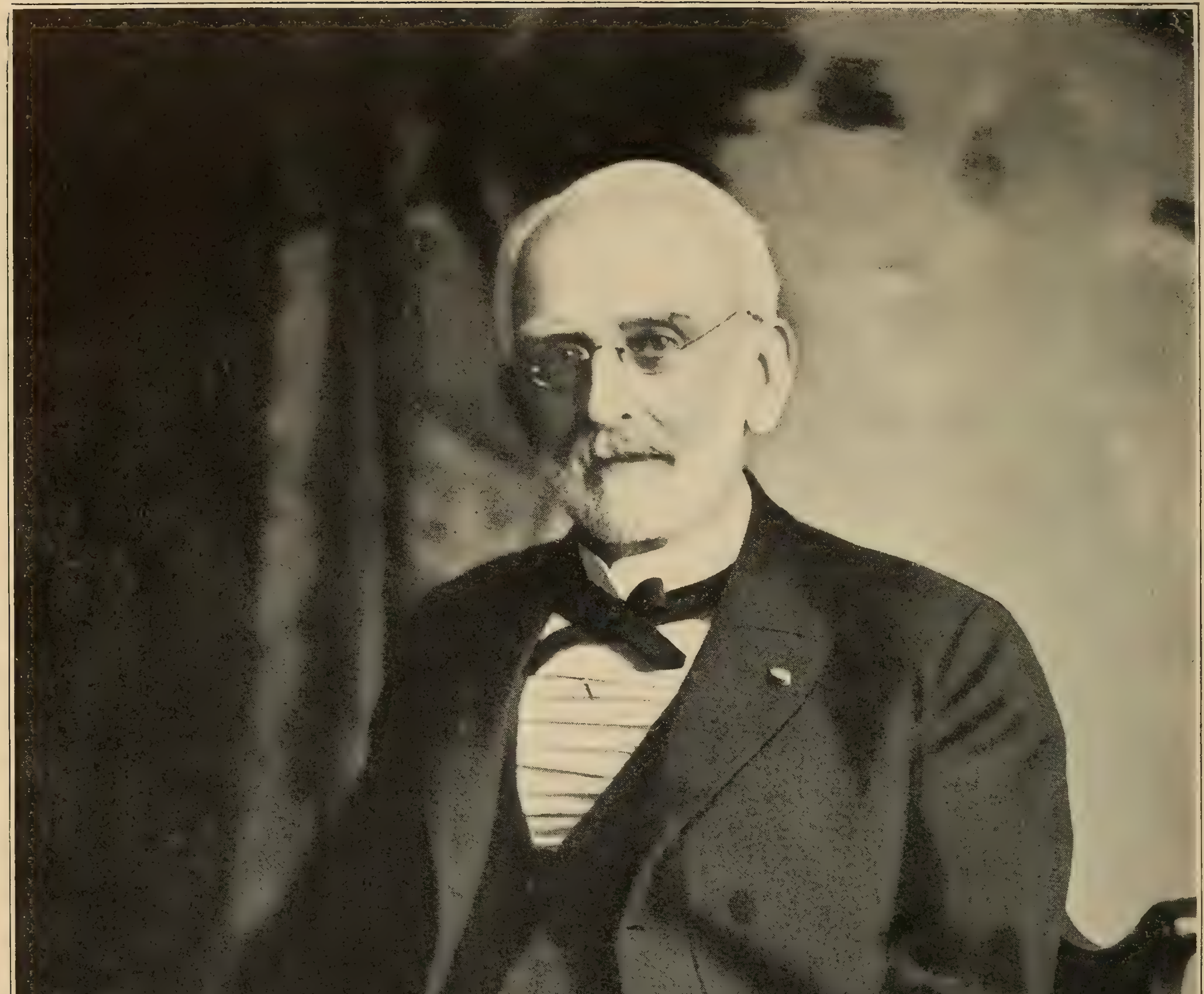

Peter Neff.

1885. A geological hand atlas of the 67 counties of Pennsylvania, embodying the results of the field work of the survey from 1874–1884. *Second Geol. Survey Pennsylvania*, Report X, pp. cxii, 61 plates.

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- The coal beds and fireclays of the Wellersburg basin in Somerset county. Pp. 227–239.
- Some general considerations respecting the origin and distribution of the Delaware and Chester kaolin deposits. Pp. 571–591, with map in atlas.
- Some general considerations of the pressure quantity, composition, and fuel value of rock gas, or the natural gas of the oil regions of Pennsylvania, pp. 657–680.
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In addition to the papers and volumes already mentioned, Professor Lesley prepared elaborate prefaces and letters of transmittal to accompany the reports of his assistants on their respective districts, not less than twenty-four in number. In compiling this list the writer has made full use of Mr Darton's work.*

In the absence of the author the following memoir was read by Samuel Calvin:

MEMOIR OF PETER NEFF

BY H. P. CUSHING

Peter Neff, late Fellow of this Society, was born in Cincinnati, Ohio, April 13, 1827. Three or four generations of both paternal and maternal ancestors had lived in this country and had been active and influential citizens. The boy had extra good school advantages for the time and prepared for Yale college, which he entered in 1845. Owing to feeble health he was obliged to leave college at the end of his freshman year and to spend a year in travel, meanwhile keeping up his sophomore studies. The succeeding autumn he entered Kenyon college, from which he graduated in 1849. The next two years were spent in charge of an Illinois farm belonging to his father, but the life did not accord with his inclinations, and he returned and entered the theological seminary at Gambier, getting his degree in 1854. At the expiration of two years spent in the ministry his health became again uncertain, an annoying throat trouble especially proving an obstacle to the practice of his profession. He did not withdraw from the ministry until ten years later, and did occasional ministerial work during the interval, but his time was mainly occupied with other pursuits.

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* Catalogue and index of contributions to North American geology, 1732–1891. By Nelson Horatio Darton. U. S. Geol. Survey, Bull. No. 127, 1896.

During 1853–1854, at Gambier, he had been associated with Professor Hamilton L. Smith, of Kenyon, in experiments to perfect his invention of taking pictures upon iron plates. He obtained a patent "for the use of japanned metallic plates in photography" in 1856, and built a factory for japanning plates in Cincinnati. These he called "melainotype" plates. To aid in their introduction he published a pamphlet describing the process and a booklet which was a general treatise on photography on collodion. About this time he invented and patented a varnish for melainotypes and collodion pictures. In 1856 he was awarded a bronze medal by the American Institute, New York, for the best melainotypes. In 1859 he sold his factory and buildings and went out of the business. An exhibit was made at Philadelphia in 1876, it being labeled "Relics of Photography." The material comprised in this exhibit was later turned over to the Smithsonian Institution at its request.*

In 1860 Mr Neff went to Gambier to reside, lived an out-of-door life, and became interested in the local geology. Noting the so-called oil signs in the region, he visited and studied the Oil Creek territory, in western Pennsylvania, in 1864. With the knowledge thus gained in hand he commenced a reconnaissance in southern Ohio. To use his own words, he "felt that on the western border of the Appalachian basin there must be a duplicate of the Venango oil territory." Commencing at the Ohio river, he followed the strike of the Waverly rocks to the northward until, in Coshocton county, he decided that he had found the territory he sought. He leased land for drilling and made an areal map of Knox and the western portions of Coshocton and Holmes counties, a map so correct that it was practically adopted by the succeeding geological survey of the state.

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*Smithsonian Report, 1891, part 2, pp. 797 and 821.

His first well pierced the Berea sandstone in June, 1865, and a strong flow of gas resulted, which threw the water out of the well to a height of 150 feet. This was the so-called "Geyser well," which obtained considerable notoriety at the time, the mixture of water and gas being spouted from the well at intervals of one and one-quarter minutes. The second well was completed the next year, successfully cased after a plan of his own, which he was strongly advised would not be efficacious, entered the Berea sand dry, and obtained a large flow of high-pressure gas. In all he bored a considerable number of wells, scattered over quite an area, for the purpose of defining the limits of the territory. He kept careful records and samples of all of them, a quite unusual procedure at this early day, being moved thereto solely by his interest in the geology of the district.

Being in doubt regarding some matters pertaining to the geology of the region, he, in 1866, engaged Professors J. S. Newberry and A. Winchell to unite in an investigation. Their report, which was corroborative of his own work, was published in a pamphlet of the "Neff Petroleum Company."

He prepared a map and report on the geology of that portion of the state, which the member of the legislature from that district presented to the legislature for publication. Its presentation seems to have been a large factor in inducing that legislature to enact the law establishing the Second Geological Survey of the state. M. C. Read reported on this district for the survey, and made large use of the data which Mr Neff had so patiently accumulated and which were cheerfully and unselfishly turned over to him in toto. In Professor Orton's later reports on the economic geology of the state much use is made of the same material, and its importance and interest is emphatically stated."*

Mr Neff had bored for oil and found gas. The district was a remote and unsettled one and the problem before him was its utilization. He discovered in 1866 that a very fine quality of lampblack could be obtained from this gas, devised appliances for its production, for which he took out patents, and commenced its manufacture in 1875. The industry is now a large one in western Pennsylvania, which district is much more advantageously situated, but the process used is practically the one laboriously and successfully worked out and first applied by Mr Neff.

In 1888 he changed his residence from Gambier to Cleveland, his son having engaged in business there. From 1893 to 1899 he served as librarian of the Western Reserve Historical Society of Cleveland. During his residence in Gambier he had made a large and important archeological collection, which now forms a part of the society's collection. Since

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*Geol. Survey of Ohio, vol. iii, pp. 340-347, and vol. vi, pp. 340-343.

1899 he had lived quietly in Cleveland with his family. He died on May 11, 1903.

Mr Neff was one of the original Fellows of this Society. He was seldom able to attend its meetings and was probably unknown to the great majority of its members; but the Society was very dear to him, and his pride in its growth and vigor was great. He was not a professional geologist, and such active part as he took in geologic work was from the standpoint of applied geology; but he had an acute interest in the general subject, read widely, and was ever ready to do what he could for the advancement of the science.

My own acquaintance with Mr Neff dates only from 1893. In passing the Historical Society building I used frequently to go in and enjoy a few minutes' chat with him. His favorite occupation, stated in his own words, was "tramping over the country." He wanted to find out about things. He liked to find them out himself, but it was the things that interested him, not who found them out. During my talks with him I never once heard him refer to his own exploits. His discoveries were always at the service of any one who could use them. His interest in geology was in its progress. That was the important matter—not to whom the progress was due. It was a pleasure to him to feel that he had done something for the advancement of geology; but he fully appreciated that in the advancement of knowledge the single individual counts for little.

There is little bibliography. From a man of his nature and pursuit that was to be expected. He did not feel himself a geologist, but simply one interested in geology. The results of his geological work were freely made over to others to use. The single short paper communicated to this Society and published in its Bulletin* is, so far as I can discover, his sole contribution to geology published over his own signature. It in no way measures the indebtedness of geology to him.

MEMOIR OF WILBUR CLINTON KNIGHT †

BY ERWIN H. BARBOUR

Though others might render the service better, it seems fitting, nevertheless, that tribute be paid to the memory of Doctor Wilbur Clinton Knight by a contemporary living near his early home, associated with his Alma Mater, and with his work for advanced degrees. In his college days, as well as in his maturer years, he was a man of peculiar rectitude. Being possessed of strong personality and great strength of

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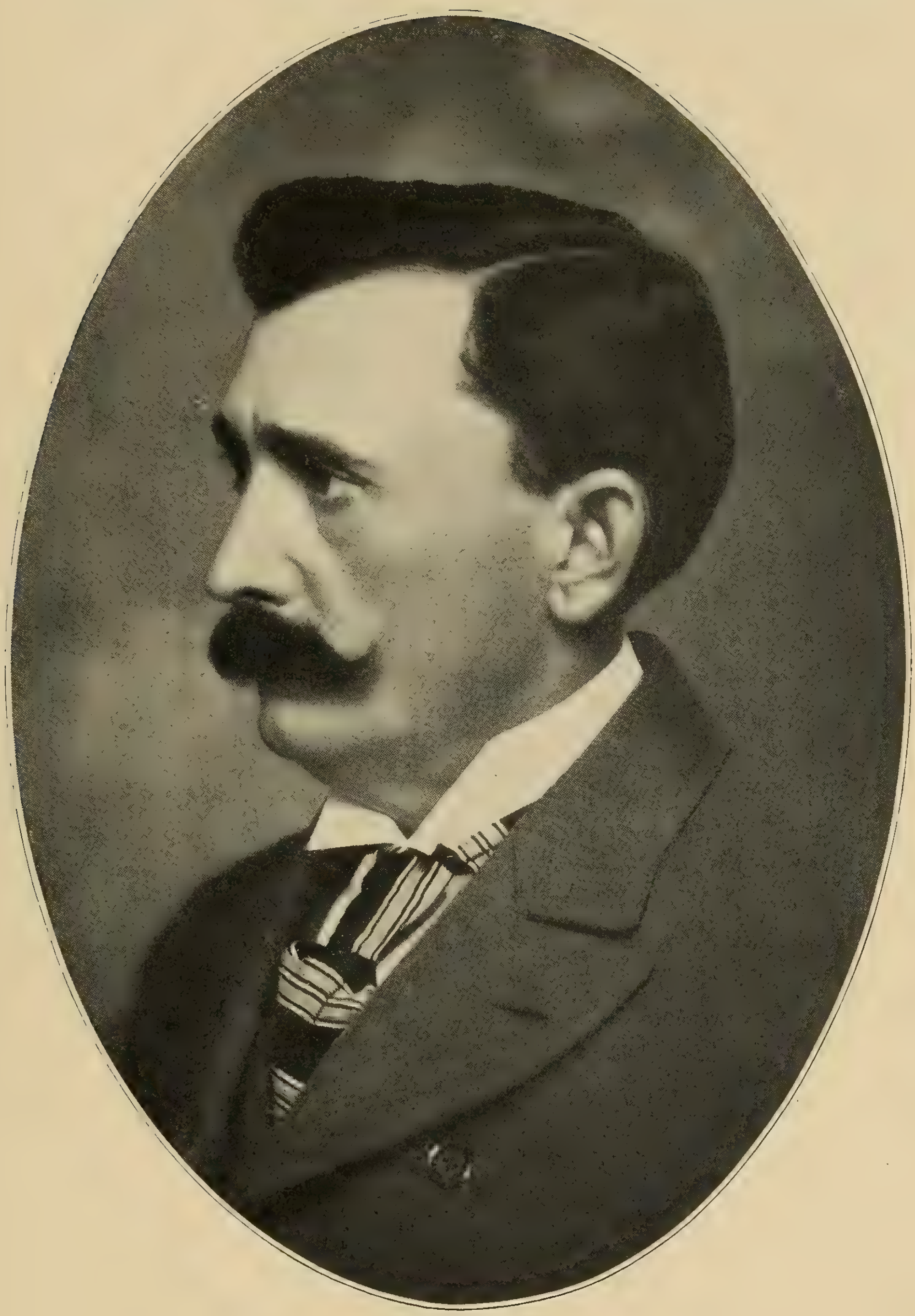
* The Sylvania sand in Cuyahoga county, Ohio. Bull. Geol. Soc. Am., vol. 1, pp. 32-34.

† As Professor Barbour was called away from the meeting this memoir was not read, but it is inserted here in its proper place.



Wilbur C. Knight

character, balanced by a fine physique and a clear mind, he was preeminently the man for the place he held in the state of Wyoming. Though an indefatigable worker and leading a strenuously active life from boyhood, he never became so engrossed in his own affairs as to wholly forget his public and social obligations. To a large degree he was a self-made man, yet without a tinge of arrogance or self conceit. He was born December 13, 1858, at Rochelle, Illinois, from which place his parents, Mr and Mrs David A. Knight, moved to a farm at Blue Springs, Nebraska, some 30 miles south of Lincoln, where they still live.

Thus his boyhood days savored of the arduous struggle of frontier life on a farm, which may have been none the worse for him, since his fearlessness, physique, fixity of purpose, and scientific bent may have been engendered by it. His scientific tastes and tendencies were made known to his parents by the nature of his pastime and by his choice of reading matter, and to his instructors in the University of Nebraska by his chosen courses of study. Though an excellent botanical student and particularly devoted to chemistry and assaying, his special aptitude was for geology and mineralogy. While still an undergraduate student young Knight, during the protracted absences of his instructors in geology, voluntarily organized classes, prescribed courses of readings, and planned and carried out laboratory work and field excursions, thus early evincing his ability to plan and execute, which later in life made him so invaluable to the state of Wyoming. Though an ardent student, full of college spirit, and a scholar of excellent standing, he did not neglect those obligations which lie outside of the curriculum and go so far toward making men versatile, broad, and liberal.

As an undergraduate student he took an active part in the literary, debating, and social societies. Being musically inclined, he organized the University band, in which he played. This organization flourished and still survives him as the present Cadet band, numbering some fifty pieces, now under military discipline and under the directorship of a competent bandmaster. Though subordinated to other work, his music was never wholly abandoned.

In 1886 he was graduated from the University of Nebraska with the degree of Bachelor of Science. The same year he was appointed assistant territorial geologist of Wyoming. Surrounded as he was in a frontier mining region by many unscrupulous men and by fraudulent practices, a test was made of the man in the outset, and his character proved to be inflexible, as every mining camp in the state of Wyoming and beyond will attest. Some of his encounters for honesty and uprightness during his early experiences were of a fairly tragic order, but he avoided even the appearance of irregularity.

In 1887 he established himself as an assayer at Cheyenne. From 1888 to 1893 he was superintendent of mines in Colorado and Wyoming. During these years he had pursued courses of study leading to the degree of Master of Arts, conferred by the University of Nebraska in 1893. He served as state geologist from 1898 to 1899, and was professor of geology in the University of Wyoming, at Laramie, to the time of his death. Having been granted a leave of absence for the two years past, he was serving as an oil expert for the Belgo-American Oil Company.

After traveling and studying abroad, and after following a course of special instruction in the University of Chicago, he spent several years in continuous graduate work in the University of Nebraska, and received the degree of Doctor of Philosophy June 7, 1901.

In spite of hard work, he preserved his youth and managed to find moments for the continuance of student sports on the golf link, or athletic field, or in riding, or in shooting and trout fishing. Those of us who have accompanied him on excursions in Wyoming must remember with admiration his quickness and accuracy with the gun and his skill with the rod. It was a particular pleasure to him to conduct parties of students or citizens on excursions to interesting points throughout the state, whether for the purposes of scientific exploration or in the pursuit of pleasure, recreation, and rest. His largest undertaking of this kind was the Fossil Field Scientific Expedition of 1899, when some three hundred colleges and scientific societies were invited to send delegates to join him for a summer's collecting trip in the famous fossil fields of Wyoming.

Out of deference to this ambitious undertaking, the Union Pacific Railroad company, through Mr A. Darlow, rendered most courteous aid by offering complimentary transportation over this line for the entire company. Doctor Knight furnished camp equipments, teams, cooks, guides, and provisions for a party of about 100, comprising representatives from every part of the United States, as well as from Canada, England, Scotland, and Germany. The result of this expedition, conceived of, organized, and successfully conducted by Doctor Knight, was the closer relation of widely separated naturalists and investigators, their familiarity with classic collecting grounds and field methods, and the discovery of many new facts which have been or are to be published. His plan in this connection, as confided to a few friends, was the organization of annual expeditions to be conducted at small cost and open to all students and teachers the world over desirous of rest and study. Could these plans have been carried to fruition on lines as broad and liberal as those of which he conceived, there is no doubt of the resulting educational value.

Having charge of the geological expeditions sent out annually by the University of Wyoming, he had greatly systematized the work of collecting, had purchased land, had built permanent camps, and had competent helpers in the field, making collections which were destined to become famous and of great instructional value. Though actively engaged in the chemical side of geological work, his sympathy was for biologic investigations, and it was his intention, as plainly expressed, to gradually restrict his efforts to paleontology, more particularly vertebrate paleontology. To this end he had already filled the museum of the University of Wyoming with rich vertebrate collections, especially Oligocene mammals and Jurassic Dinosaurs.

He had amassed a great collection of valuable material, much of which is new and yet to be figured and described, but his knowledge of facts and conditions concerning the economic resources of the state was of particular significance to the commonwealth, for there was no spot which he had not visited. Those outside of the state, as well as those living in it, can not but deeply regret that so much is lost to science by a man at the very prime of his life. After an illness of about one week, resulting from peritonitis with complications, Doctor Knight died at his home, in Laramie, Wyoming, July 28, 1903, at the age of forty-four years. In 1889 he was married to Miss Emma Howell, a student whom he had known in the University of Nebraska, and those of us who knew him intimately in his own home understand the perfection of his domestic relations. He leaves a widow, one daughter, and three sons. He was honored by election to a number of learned and fraternal societies, being a member of the National Geographic Society, American Institute of Mining Engineers, a Fellow in the Geological Society of America, a member of the scientific fraternity Sigma Xi, an honored Mason, and a member of the Congregational church. For the past few years he had been connected more or less intimately with the work of the United States geological and hydrographic survey. He was a man of action, and only those favored with intimate acquaintance are fully aware of the vigor, as well as the conscientiousness, of his work and the magnitude and scope of his plans for the future.

It is seldom, indeed, that the influence of any one scientist touches every one in his state so intimately that the commonwealth mourns his loss as the state of Wyoming mourns the loss of Doctor Knight, its unimpeachable geologist.

Of his many virtues the one which left its mark throughout all that vast region was his absolute integrity.

His list of papers and scientific contributions, though long, was but introductory. He had but begun to publish, and, as his intimates well know, the next few years were to have been unusually fruitful of results.

The loss which geology sustains is all the greater because such a mass of facts not yet transcribed to paper, but confided, instead, to an unerring memory, are beyond recovery.

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Following the reading of the memoirs several announcements were made concerning administrative details and appointed events of the meeting, after which the President declared the scientific program in order.

The first paper presented was the following:

GEOGRAPHY AND GEOLOGY OF WESTERN MEXICO

BY OLIVER C. FARRINGTON

[*Abstract*]

This paper describes a journey from Durango westward to Ventanas across the plateau of the western Sierra Madre. The plateau exhibits a comparatively un-

broken surface, rising gradually from a height of 6,000 feet at Durango to about 9,000 feet farther west. It then slopes toward the Pacific and is deeply dissected by streams. Evidence is adduced to show a rather rapid eastward movement of the divide.

The region is for the most part comparatively arid, although on the western edge of the plateau extensive forests occur. The rocks are largely eruptive. The Cerro Mercado or "Iron mountain" is described in some detail and its origin discussed, as is also the area of remarkable forms produced by erosion known as the "City of Rocks."

This paper is published in Publications Field Columbian Museum, Geological series, volume 2, number 5.

In discussion of the paper remarks were made by W. M. Davis, the President, and the author of the paper.

The second paper was

STUDIES IN THE AMMONOOSAC DISTRICT OF NEW HAMPSHIRE

BY C. H. HITCHCOCK

Remarks were made on the paper by W. H. Hobbs. The paper is printed as pages 461–482 of this volume.

The third paper presented was

FINGER LAKE REGION OF WESTERN NEW YORK

BY CHARLES R. DRYER

The paper was discussed by H. L. Fairchild, W. M. Davis, R. D. Salisbury, R. S. Tarr, S. Calvin, and the author. It is printed as pages 449–460 of this volume.

The following paper was read by title:

FOSSIL WATER FUNGUS IN PETRIFIED WOOD FROM EGYPT

BY ALEXIS A. JULIEN

[*Abstract*]

A description is given of a specimen of silicified wood from a "petrified forest" near Cairo, and the mode of distribution of the fungus throughout its ducts. An interesting association of crystals of hematite and of pseudomorphs after gypsum and halite occurs, which testifies to the earlier conditions of petrifaction. The organic forms have been preserved in remarkable perfection and abundance. These are successively described, comprising discoid spores, an articulated macromycelium, macrosporanges inclosing sporules, micromycelium bearing three forms of stalked cells, and large ovate capsules carrying the spores first described, a continuous series which apparently represents the life history of the new organism. Its generic relationships and genetic local history are then discussed.

The last paper of the morning session was the following:

SUDBURY NICKEL-BEARING ERUPTIVE

BY A. P. COLEMAN

[*Abstract*]

It has long been known that the deposits of nickeliferous pyrrhotite of the Sudbury region, Ontario, are associated with bands of a peculiar eruptive rock, generally called diorite, but really norite, passing gradually into micropegmatitic granite. Two ranges have been distinguished by prospectors, a southern and a northern, the best known ore deposits being at the basic margin of the southern range or on dike-like offsets from it. During the past summer work carried on for the Bureau of Mines of Ontario has proved that the two ranges are joined at the ends, forming an oval basin 37 miles long and 15 miles wide. The band of eruptive rock, which has a width of from 1 to 4 miles and averages nearly 2 miles in thickness, dips inward on all sides and evidently forms a synclinal trough inclosing an area of pyroclastic and ordinary sediments of doubtful age (Cambrian or Upper Huronian). Both the upper and lower sides of the synclinal sheet are in eruptive contact with the adjoining rocks, the acid edge with the sediments just mentioned, the basic edge with Laurentian gneiss or Huronian quartzites or schists.

Taken as a whole, the eruptive sheet is of a laccolithic character, but unlike any other known laccolith in shape and dimensions, since it probably includes at least 600 cubic miles of rock. The ore bodies are often large, and one mass, the Creighton mine, contains more than 3,000,000 tons of pyrrhotite. Those at the basic edge of the sheet blend into the general mass of the norite and must be looked on as due to magmatic segregation, perhaps by gravity, as they are all found in bay-like depressions of the country rock on the outer or lower side. The ore bodies on offsets are partly formed by cooling from the molten condition, but generally show evidence of the action of circulating waters, and may pass into ordinary vein deposits not evidently connected with norite.

The synclinal form of the sheet is supposed to be due to the sinking of the substratum owing to the removal of molten material from beneath. The observed inward dip of the lower surface of the sheet averages about 45 degrees, and the thickness of sedimentaries included within the syncline shows that the center must be several thousand feet below the surface.

Professor Coleman's paper was discussed by the President, G. K. Gilbert, and W. H. Hobbs.

The Society adjourned for the noon recess.

At 2 o'clock p m the Society reconvened, and the first paper read was the following:

WIDESPREAD OCCURRENCE OF FAYALITE IN CERTAIN IGNEOUS ROCKS OF WISCONSIN

BY SAMUEL WEIDMAN

[*Abstract*]

In the central part of Wisconsin, within the area of pre-Cambrian rocks, is a large variety and abundance of igneous rock which intrudes a much older sedimentary series, and, in turn, lies beneath a later sedimentary series. These igneous rocks may be divided into three series, the oldest being rhyolite, the next diorite gabbro and peridotite, the latest granite, quartz-syenite, nepheline, sodalite, and aegerite syenites and related rocks. In the last mentioned series fayalite occurs as a persistent, though minor, constituent. It was separated from the rock and analyzed. Phases of the rock and a number of the minerals contained were also analyzed.

The series in which the fayalite occurs is quite similar to the nepheline-bearing and associated rocks of Arkansas, of southern Norway, and of Essex county, Massachusetts. It differs from them, however, in containing a much smaller amount of magnesia, there being no increase in amount of magnesia as the content of silica in the series decreases. The pyroxenes, amphiboles, and micas present contain very little magnesia, being those rich in lime, iron, and the alkalies. Fluorite is a persistent, though not an abundant, constituent of these rocks.

The fayalite occurs in the quartz syenite, having a silica content of 61.18 per cent, and to a very small extent in the amphibole-granite, bearing 67.99 per cent of silica. In phases of the quartz syenite it probably constitutes from 1 to 5 per cent of the rock, and was noted in many thin-sections of this rock from widely different parts of the district. In the rocks bearing quartz it is associated with the feldspars, orthoclase, albite, and microperthite, with the calcium-iron-amphibole, arfvedsonite, with the calcium-iron-pyroxene, hedenbergite, and with iron-mica containing large amounts of potassium. In phases of the non-quartzose and nepheline-bearing rocks of the series the fayalite also contributes a fraction of 1 per cent to as much as 5 per cent of the rock. In some of the nepheline-rich rocks the fayalite is the only dark-colored mineral noted in the thin-section. In the latter rocks the fayalite occurs with orthoclase, microperthite, nepheline, sodalite, the soda-amphiboles of the riebeckite and crocidolite type, and the calcium iron pyroxene, hedenbergite, and the potash iron mica, lepidomelane.

The idea has prevailed, to some extent at least, that fayalite had only an aqueo-igneous origin in rocks rather than ordinary igneous origin. The fayalite in these rocks, however, has the associations and relations of a normal, original constituent. It does not occur in veins, segregations, or cavities, nor does it occur in idiomorphic crystals. It is distributed throughout the rock and assumes in its development such shapes as are due to the mutual interference of surrounding minerals, like the quartz, feldspar, nepheline, and common rock-forming minerals with which it is associated.

The alteration of the fayalite is described, and the previously noted occurrences are referred to.

Remarks on the paper were made by U. S. Grant and O. C. Farrington. It is published in Journal of Geology, volume xii, pages 551–561.

The second paper presented was

FIELD WORK IN THE WISCONSIN LEAD AND ZINC DISTRICT

BY U. S. GRANT

[*Abstract*]

During the summer of 1903 the Wisconsin Geological and Natural History Survey conducted some detailed mapping of selected areas in the southwestern portion of

the state, which region is a part of the Upper Mississippi Valley lead and zinc district. In this field work, which was carried on under the direction of the writer, the topographic and geographic mapping of the district were conducted at the same time. Each individual doing part of the mapping was furnished with a small planetable, an alidade sight ruler, an aneroid barometer, and a Locke hand level. Preliminary to the mapping bench-marks had been established at intervals of one-fourth mile or less along the roads of the district mapped, the date for these bench-marks being obtained by leveling from established bench marks of the United States Geological Survey. As the roads are rarely more than a mile apart—usually within half a mile of each other—the opportunity for careful topographic mapping was good, and the use of the aneroid barometer was made satisfactory by the ability to check on the bench-marks at short intervals of time. For general locations the mapping depended on the roads of the district, which usually run along section lines, and on the subdivisions of the farms, which usually correspond to the fractional section lines. Locations, aside from these, were drawn in by intersections and by pacing.

Along with the topographic work geological mapping was done, all the important outcrops being located and the contacts between the different formations being determined as to elevation by the barometer and in some cases by leveling. The field maps were made on the scale of 8 inches to the mile, which will be reduced to 4 inches to the mile on the published map. The contour interval used was 10 feet. The rocks of the district consist in general of undulating Paleozoics; and one important horizon, namely, the base of the Galena limestone, which is an important horizon in stratigraphy as well as in the mining carried on in the district, was carefully located. It is expected that the altitude of the base of this formation will be shown on the finished maps by a series of contour lines. The maps of this scale and detail are expected to be valuable in themselves, and it is also hoped that they will give important results in working out the details of the relations of the ore bodies to the geological structure of the district.

Remarks were made on Professor Grant's paper by F. E. Wright.

The third paper was

MOLYBDENITE AT CROWN POINT, WASHINGTON.

BY A. R. CROOK

This paper is printed as pages 283–288 of this volume.

The fourth paper was

PHYSIOGRAPHY OF THE OZARK REGION OF MISSOURI

BY C. F. MARBUT

The paper was discussed by C. W. Hayes, A. H. Perdue (a visitor), W. M. Davis, and the author.

The fifth paper was

PHYSIOGRAPHY AND GLACIATION OF THE WESTERN TIAN SHAN MOUNTAINS, TURKESTAN

BY W. M. DAVIS AND E. HUNTINGTON

[*Abstract*]

The existing ranges of the Tian Shan mountains in central Turkestan result from the elevation and greater or less dissection of a more ancient mountain system that had been previously subdued or worn down to small relief over a large area. The elevation of the old mountain region was accomplished in part with moderate deformation, in part with strong block faulting. Local glaciation in several successive epochs is clearly recognized.

The paper was discussed by G. F. Wright, G. K. Gilbert, A. P. Coleman, and the author.

After some announcements, the sixth paper was presented:

SYSTEM OF KEEPING THE RECORDS OF A STATE GEOLOGICAL SURVEY

BY E. R. BUCKLEY

The seventh and last paper of the day was

TECTONIC GEOGRAPHY OF SOUTHWESTERN NEW ENGLAND AND SOUTHEASTERN NEW YORK

BY WILLIAM H. HOBBS

[*Abstract*]

The former assumption of deformation of the New England area by a system of folds not modified in an important way by fault structures has led to much confusion, and the hypothesis has now proven inadequate to satisfactorily explain the present positions and attitudes of the rock masses. The rôle which block faulting may have played in the deformation of the area is suggested by the complex mosaic of fault blocks shown to be present in the Newark rocks of the Connecticut valley, the Pomperaug valley, and also worked out in less detail for the type Newark area of New Jersey. The recent work of Crosby in the Boston basin, of Hitchcock on the northeastern margin of the White mountains, of Cushing to the west of lake Champlain, of the latter and also of Kemp in the Adirondacks district, and of Grabau in Becraft mountain in southeastern New York; all emphasize the importance of normal fault structures and show that a chain of areas encircling the southern New England province have each a crustal architecture resulting from normal faulting. The elements in these structures may, with perfect propriety, be likened to blocks of a mosaic, only in this case disturbed from the normal mosaic condition of uniformity of altitude.

In a series of papers the author has called attention to the importance of fault structures within the southern New England area, and in the latest of these* has outlined an investigation by newly derived methods for the discovery of fault structures and for the determination of their system within the southwestern New England province. Without here recounting these methods, which have been elsewhere briefly described,* it may be stated that the most important respect in which they differ from established methods of attack upon tectonic problems of the crystalline schists lies in the observation of the orientation of topographic and hydrographic features and geologic boundaries. Another departure from established methods has been to study with detail, which by contrast is almost microscopic, very limited areas which are distinguished for their complexity of areal relations. Within these areas the study is intended to develop the essential nature of the deformation of the districts in which they lie—the relative importance of fold and fault structures and the dominant elements in each system—so that they may be regarded in some sense as *key areas* for the study of the province.

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* The geological structure of the southwestern New England region. Am. Jour. Sci., vol. 165 1903, pp. 437-446.

Five areas of this kind—the Lee (Massachusetts) ridges, the near-lying Evergreen Hill area, the Twin Lakes (Connecticut) Valley area, the Pomperaug (Connecticut) valley, and the Greater New York City area—have now been studied and the dominant influence of fault structures established for each. The joint system of each area has also been studied and its relation to the orientation, to the topographic and hydrographic lines (the *lineaments*), and to the geologic boundaries has been considered. The dominant joint system has been found in each area to be vertical or nearly so, the joint planes falling within a considerable number of parallel series, of which a comparatively small number greatly outweigh all the others in importance. The majority of directions of joint series are found to be in essential agreement between the different areas, though certain directions have been observed in particular areas only, and it would appear that in a few cases a series in one area may be replaced by a near-lying series in another.

A principal aim of the investigation has been to determine whether the fault planes within the area fall into a system in essential agreement with the joint system, as has been elsewhere determined by Daubrée and Brögger. If the methods derived are to be trusted, the study fully confirms the view of these geologists, who have seen in the system of joints the first effect of the deformation of a province by fracture. The author's view is that the release of compressive stress incident to the formation of the planes of separation (joints) reduces the competency of the crustal block to sustain loads, reduces its rigidity regarded as a girder, and allows of the differential movements of its parts along the joint planes, in which the idea of faults inheres.

Having examined the *key areas* and having found a combined system of joints and faults in each, the investigation naturally turned in the direction of comparing the lineaments in the districts surrounding these areas with the joint and fault system made out. The following table indicates the relationships between the lineaments in these districts and the joint directions which were observed. The district surrounding the Lee ridges and the near-lying Evergreen hill has been designated the Stockbridge valley, that surrounding the Twin Lakes area the Sheffield valley.

In bringing about the present positions and attitudes of the rock masses, and in producing the present topographic lines, it is concluded that folds, though everywhere apparent, have been altogether subordinate to the mosaic produced by the differential movement of orographic blocks. In a large measure this is true because

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* The mapping of the crystalline schists. Jour. Geol., vol. x, pp. 782-791, 858-890.

Stockbridge Valley area, partial.			Sheffield Valley area.			Pomperaug Valley area.			New York City area.			
Earth linea-ments.	Number mapped.	Observed joints.	Earth linea-ments.	Number mapped.	Observed joints.	Earth linea-ments.	Number mapped.	Observed joints.	Earth linea-ments.	Number mapped.	Observed joints.	Total.
Degrees.		*Degrees.*	*Degrees.*		*Degrees.*	*Degrees.*		*Degrees.*	*Degrees.*		*Degrees.*	
N. 5 W.	10		N. 4½ W.	12	N. 5 W.	N. 5 W.	48	N. 5 W.	N. 5 W.	9	N. 5 W.	79
N. 15 E.	10		N. 15 E.	16	N. 15 E.	N. 15 E.	20	N. 15 E.	N. 15 E.	16	N. 15 E.	62
		N. 90 E.				N. 90 E.	14	N. 90 E.	N. 90 E.	14	N. 90 E.	28
		N. 70 E.	N. 68 E.	15		N. 68 E.	2		N. 68½ E.	10		27
N. 60 W.	8	N. 60 W.				N. 61 W.	8		N. 60 W.	23	N. 60 W.	39
			N. 85½ E.	12	N. 85 E.							12
						N. 33 E.	18		N. 33 E.	8	N. 35 E.	26
									N. 28½ E.	18	N. 25 E.	18
N. 17 W.	8	N. 15–20 W.	N. 17½ W.	7							N. 30 E.	15
					N. 20 E.	N. 20 E.	2					2
N. 40 E.	4	N. 40 E.	N. 40 E.	1	N. 40 E.							7
N. 80 W.	8					N. 80 W.	1				N. 80 W.	9
			N. 37½ W.	12	N. 40 W.							12
		N. 70 W.	N. 69½ W.	20	N. 70 W.						N. 70 W.	20
		N. 50 E.	N. 50½ E.	10	N. 50 E.						N. 50 E.	10
						N. 54½ E.	60	N. 55 E.			N. 55 E.	60
						N. 34 W.	50	N. 35 W.			N. 35 W.	50
		N. 10 E.	N. 10 E.	1	N. 10 E.							1
									N. 46 E.	3		3
									N. 5 E.	1		1
									N. 30 W.	16		16
						N. 44 W.	5				N. 45 W.	5
						N. 25 W.	1			Also:	N. 25 W.	1
											N. 80 E.	
											N. 65 W.	
											N. 50 W.	
												503

the period of jointing and block faulting in which the mosaic was produced was subsequent to that of the folding. The fact that the folds have in the past absorbed the interest of geologists here and elsewhere in the study of metamorphic rocks is to be explained, it is believed, by their being everywhere prominent, so as to force themselves upon the attention, whereas the fault structures have been obscured through the agency of erosion, and are apt to be discovered only in areas exceptionally favorable to their preservation or in which the key to their arrangement has been found.

The paper is illustrated by numerous plates and figures and forms part of a paper prepared for publication by the United States Geological Survey.

SESSION OF WEDNESDAY EVENING, DECEMBER 30

At 6.30 o'clock p m the annual dinner was served at the Planters hotel, with ladies and other guests present.

At 8.30 o'clock the Society met in formal session in parlor A of the Planters hotel, and the President of the Society, Samuel F. Emmons, delivered the presidential address entitled

THEORIES OF ORE DEPOSITION HISTORICALLY CONSIDERED

The address is printed as pages 1–28 of this volume.

Following the presidential address a social reunion was held in the same room.

SESSION OF THURSDAY, DECEMBER 31

The Society met at 9.45 a m, President Emmons in the chair.

The Council report was taken from the table and adopted without debate.

AUDITING COMMITTEE'S REPORT

The Auditing Committee reported that all the accounts of the Treasurer had been found correct, and the report was adopted.

The report of the Committee on Photographs was read by the Secretary as follows:

FOURTEENTH ANNUAL REPORT OF THE COMMITTEE ON PHOTOGRAPHS

There is but little to report for the past year relating to the Society's collection of photographs. There have been no views added, but through the kindness of the Director of the U. S. Geological Survey many old prints have been replaced by new ones of finer quality and mounted on muslin; thus the bulk of the collection has been considerably diminished. The photographs are now stored in glass cases in my office, very convenient for reference.

There have been several large orders for prints by Fellows of the Society, some of the orders being due to the Catalogue with subject index published last year.

It is expected that several hundred new photographs will be added to the collection during the coming year.

Respectfully submitted.

N. H. DARTON,
Committee.

The report was adopted and the usual appropriation of $15 for the use of the committee was voted.

On motion of W. M. Davis, it was voted that the next blank issued for submission of papers should bear the list of subjects and dates of precedence.

The scientific program was declared in order, and the first paper presented was the following:

LINEAMENTS OF THE ATLANTIC BORDER REGION

BY WILLIAM H. HOBBS

The paper was discussed by W. M. Davis, C. H. Hitchcock, G. K. Gilbert, and the author. It is printed as pages 483–506 of this volume.

The second paper presented was

A PREGLACIAL PENEPLAIN IN THE DRIFTLESS AREA

BY U. S. GRANT AND H. F. BAIN

Remarks on the paper were made by R. D. Salisbury.

The following three papers were read in order without discussion.

*NEW CONE AND OBELISK OF MONT PELÉ**

BY EDMUND OTIS HOVEY

The most striking feature of the recent eruptions of mont Pelé is the cone, with its surmounting spine or obelisk, which arose within the crater of the volcano. Visitors to the crater of mont Pelé in the latter part of April, 1902, observed that a new cone, apparently fragmental in character, has begun to form beside l'Etang Sec. On May 21, thirteen days after the occurrence of the eruption which de-

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* The data embodied in this and the following two papers were obtained by the author while on two expeditions to the West Indies sent out by the American Museum of Natural History. The photographs were made for the museum, and are used as illustrations by its permission.

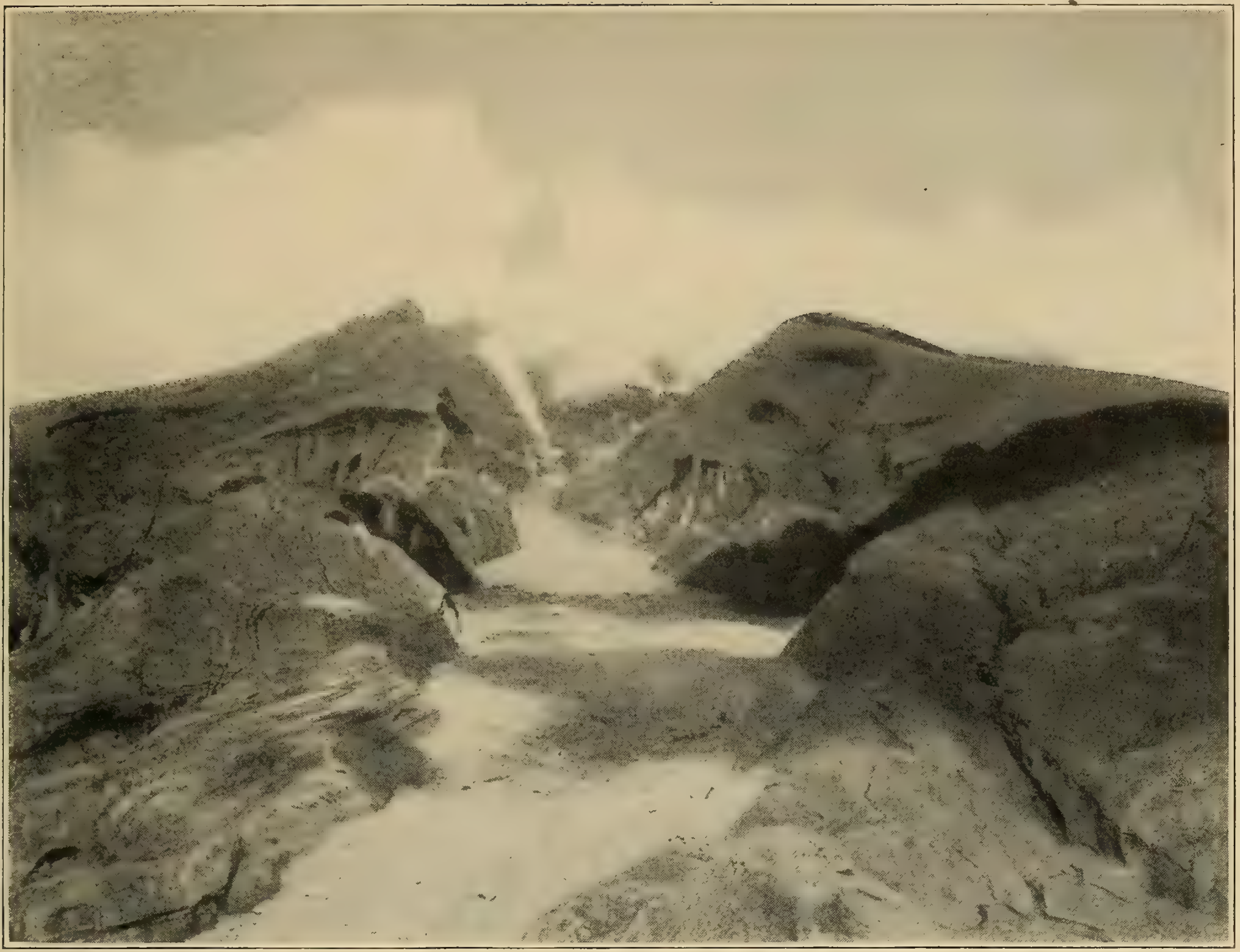

FIGURE 1.—MONT PELÉ SUMMIT FROM MORNE SAINT MARTIN. LOOKING ABOUT N. 30 DEGREES E. FEB. 20, 1903

Spine was rising rather rapidly at this time and changing in form daily. View shows also upper reaches of gorge of Rivière Blanche partly filled with light-gray ash and bombs and blocks brought down by numerous dust flows. Morne Saint Martin is about 1½ miles from the obelisk.

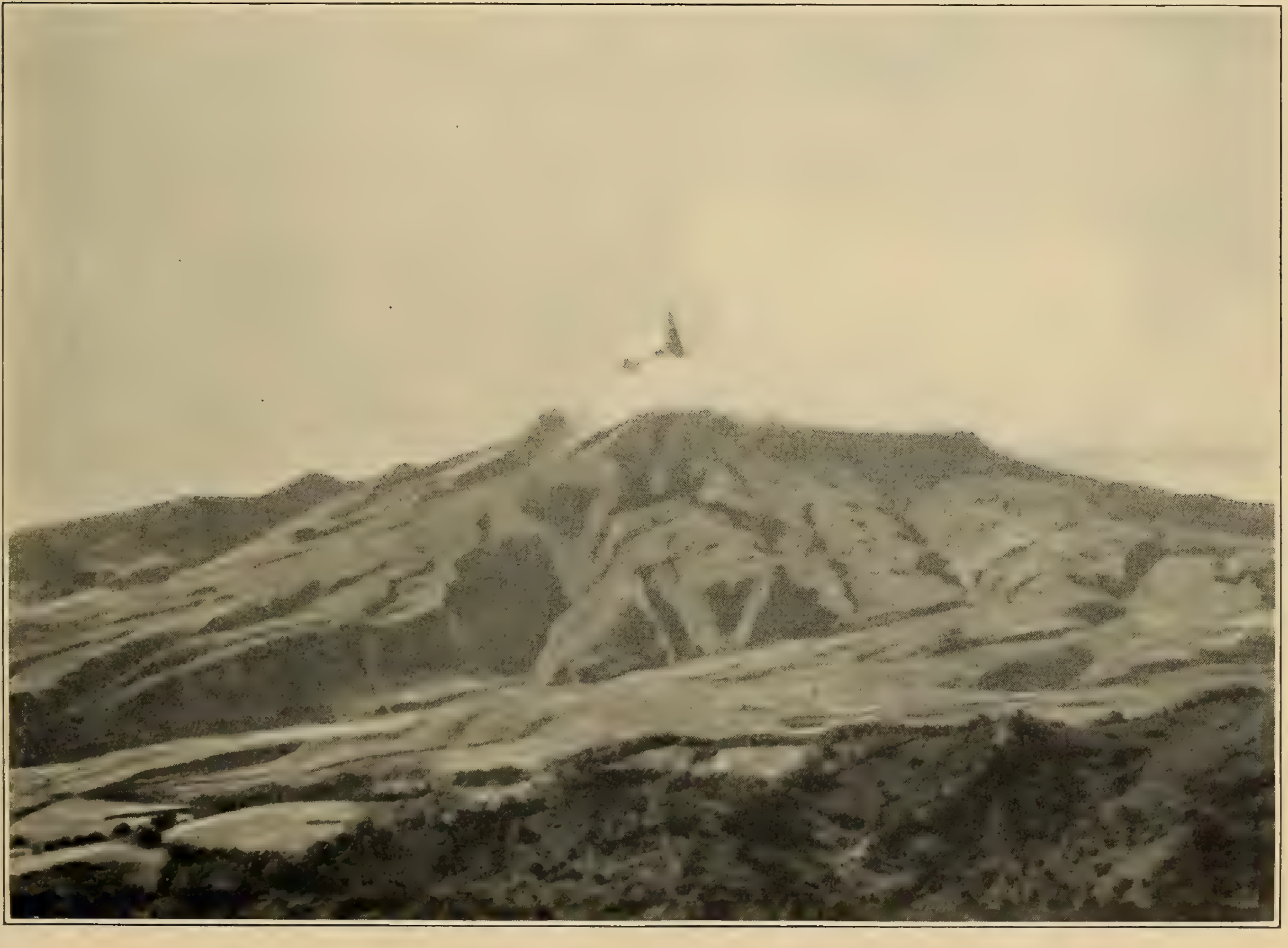

FIGURE 2.—MONT PELÉ FROM MORNE DES CADETS. LOOKING NORTH 10 DEGREES WEST. MARCH 31, 1903.

French commission's volcano observatory is about 9 kilometers (5½ miles) in a straight line from the obelisk.

MONT PELÉ

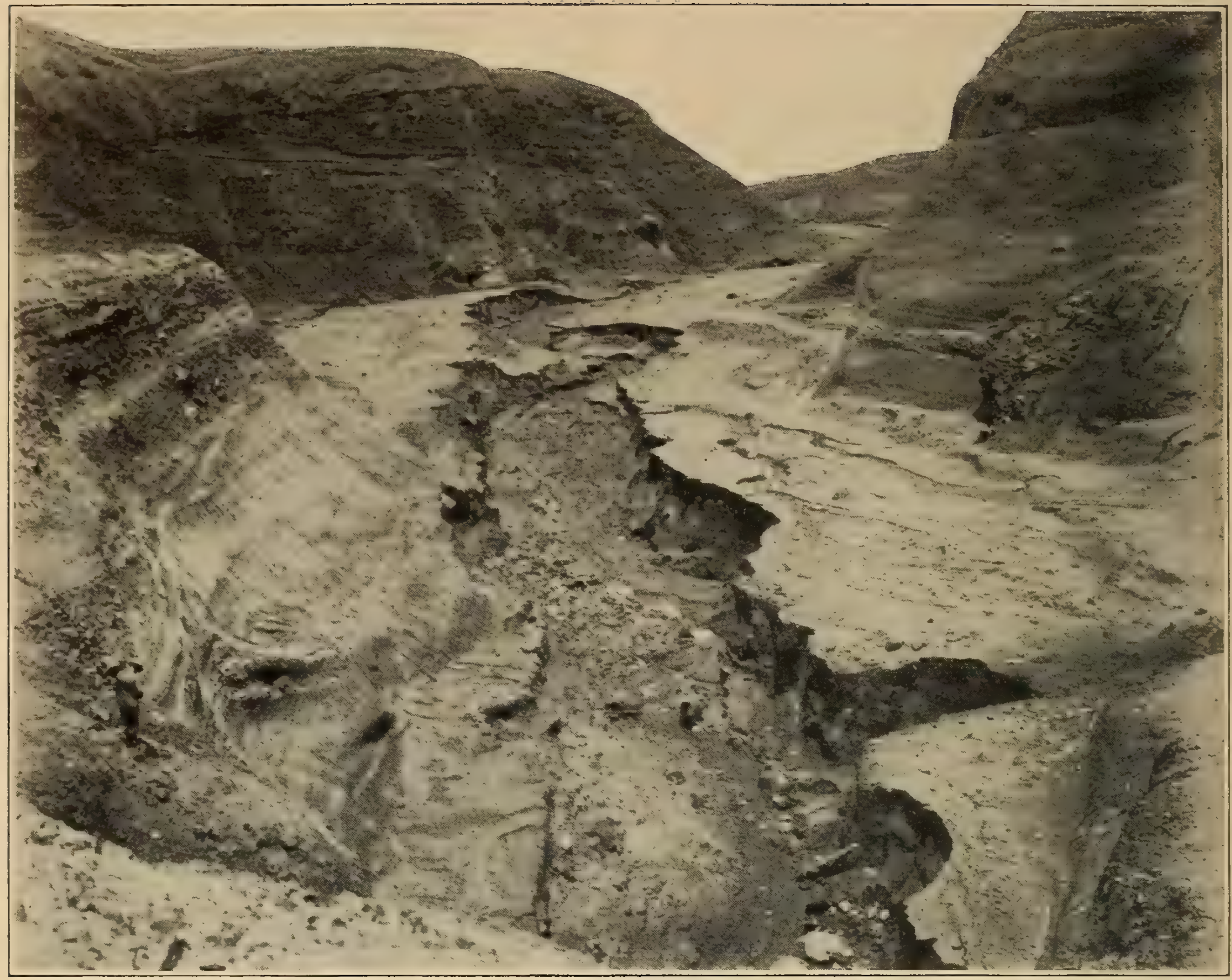

FIGURE 1.— GORGE OF RIVIÈRE SÈCHE, ABOUT ¾ OF A MILE FROM THE SEA. LOOKING SOUTHWEST. JUNE 25, 1902

Bed of new ash is shown in the gorge, which was cut into it by a mud flow on the afternoon of June 24, 1902. Gorge was deepened from 2 feet to 12 feet in less than 1 hour's time. Upper part of bluffs bordering canyon shows effects of sand-blast erosion, which, however, has carried away but little of the surface, as indicated by the uninjured condition of the artificial water way near the man standing at the left of view.

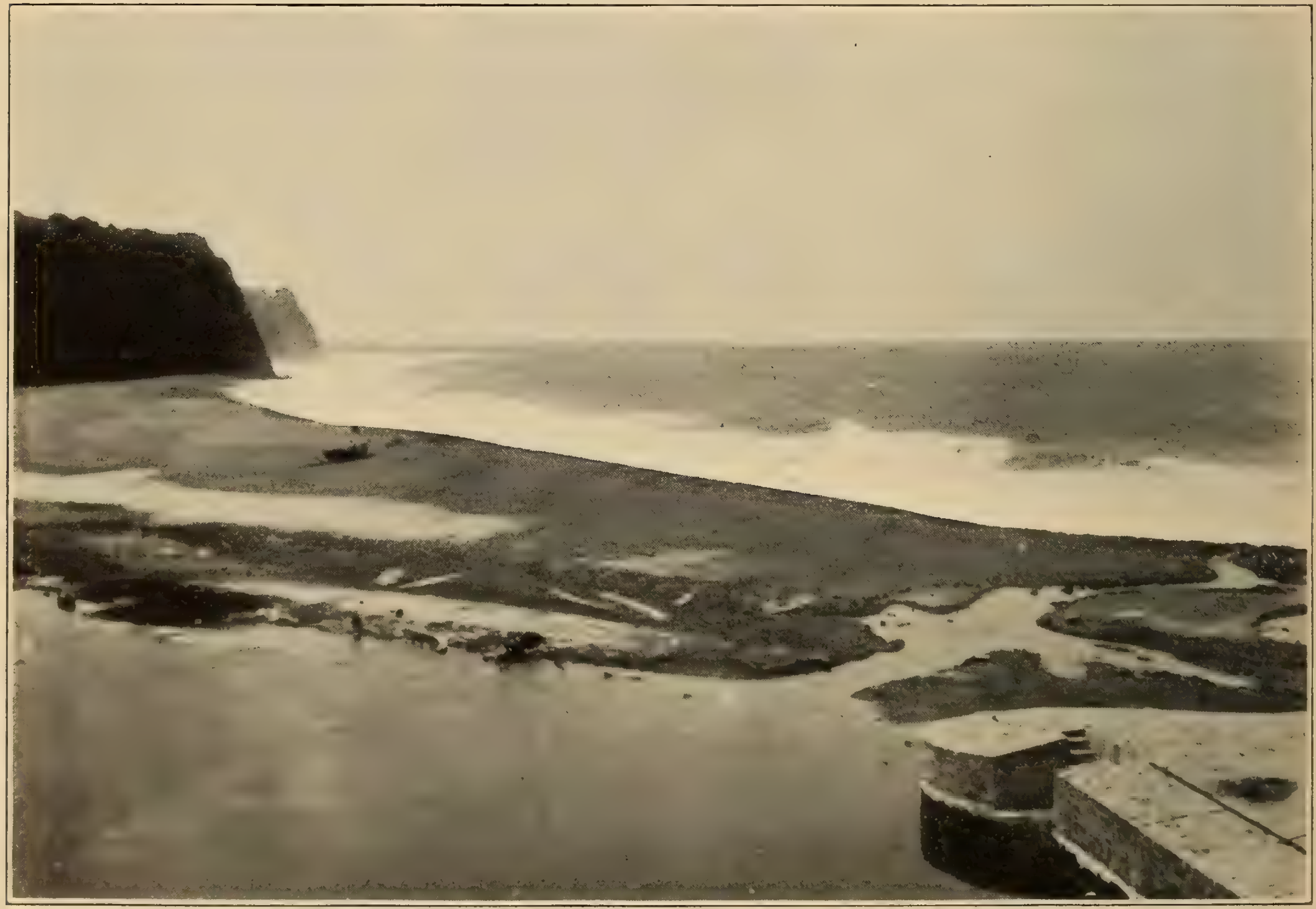

FIGURE 2.—HARBOR OF BASSE POINTE. LOOKING WEST-NORTHWEST. MARCH 25, 1903

Shows new bar and beach formed by debris brought from mountain slopes in 1902 and distributed along the coast by currents. Several great mud flows occurred in the Basse Pointe river in May and June, 1902.

GORGE OF RIVIÈRE SÈCHE AND HARBOR OF BASSE POINTE stroyed Saint Pierre, the new cone, as observed from the sea, seemed to be 500 or 600 feet in height. By the end of May the top of the cone was about on a level with the eastern rim of the great crater, indicating a growth of about 1,600 feet. In the latter part of June the height was about the same. At these times great masses of rock were observed projecting from the sides of the new cone, and early in July a mass like a shark's fin projected above its top. In August observers noted a spine surmounting the new cone, which by this time rose many yards above the old summit plateau of the mountain. In October Professor Lacroix got observations which led him to the conviction that the main body of the cone with its obelisk had been pushed up bodily from below in a solid or practically solid condition.

From October, 1902, began the growth of the wonderful spine which is the most striking feature of the eruption of any volcano within human history. The remarkable average of 41 feet per day was the record of upward growth for this portion of the mountain in eighteen days of November, 1902. On the 26th of that month the apex of the spine was 5,032 feet above the sea, or 600 feet higher than the old culminating point of the mountain, and 2,700 feet higher than the level of l'Etang Sec, the starting point of the new cone. In the succeeding five weeks about 340 feet of this altitude was lost, but in March, 1903, the spine began to rise again and finally attained an altitude of 5,300 feet above the sea near the end of May.

The usual activity of the volcano seems to have pushed this cone and spine upward, while the eruptions which took place from time to time tended toward the destruction of the spine and the disintegration of the cone. During April some of the spine was destroyed. In May the loss was recovered, but on the 30th of May 165 feet were lost from the top. During June much of the old altitude was regained, but between the 5th and 6th of August more than three-fourths of that part of the spine projecting above the cone disappeared, and mont Pelé's wonderful spine ceased to be a feature of the mountain. The loss of the spine, however, was made good in part by the elevation of the "dome" or main portion of the cone, which by the middle of October was about 400 feet higher than it had been before the loss of the spine. Since then the continued explosions in the mass have carried away the western portion of the top of the cone, leaving a sharp, almost overhanging, fin-like ridge along the eastern side of the cone. The outline, however, is changing constantly, and alternating elevation and loss of height continue.

The axis of the cone is not central within the old crater, but rises in the northwest quarter. There was a spiral valley between the new cone and the old crater, which gradually diminished in depth, and disappeared on the western and northwestern sides, where, by March, 1903, the slope of the inner cone became continuous with that of the old outer cone. In June, 1902, the author estimated this valley to be 800 feet deep, beside the remains of Morne Lacroix, on the eastern side of the crater. In March, 1903, the valley at the same place could not have been more than 200 feet deep, and the activity since that time is reported to have reduced even this depth. Judging from the debris found in the valley of the Rivière Blanche and on the rim of the crater, the material of this new cone and spine is andesite, which is partly lithoidal, partly densely vitreous, and partly pumiceous in texture. The formation of true pumice during the present series of eruptions seems to be definitely indicated by the freshness of the material of this character which is to be found scattered in loose blocks in many parts of the mountain.

A less striking but still interesting feature of the eruptions has been the filling of the gorge of the Rivière Blanche by the material brought from the crater by the numerous exploding dust clouds which have been the distinguishing feature of the numberless small eruptions that have taken place from the volcano since May 8, 1902. The lower portion of the gorge has been entirely obliterated and the adjoining plateau elevated, while the upper and deeper portion near the center has been almost filled by ejecta. The dust flows are the material left behind by the dust-laden clouds of steam. The exploding clouds of steam were so overloaded with dust and larger fragments of comminuted lava that they flowed down the slope of the mountain and the gorge like a fluid propelled at a high velocity by the horizontal or partly downward component of the force of the explosion. Many large fragments of solidified lava were carried down the gorge by these clouds. Such blocks, 10 to 15 feet in diameter, were not uncommon.

SOME EROSION PHENOMENA OBSERVED ON THE ISLANDS OF SAINT VINCENT AND MARTINIQUE IN 1902 AND 1903

BY EDMUND OTIS HOVEY

The deposition of a coating of new material, varying from a few inches to many feet in thickness, over an area embracing about 50 square miles on the island of Saint Vincent and nearly as much territory on the island of Martinique, gave an instructive opportunity for the study of the development of erosion forms under the influence of tropical rains. The new layer was thicker and more evenly distributed around the crater of the Soufrière of Saint Vincent, and hence the development of erosion features was more satisfactory there than it was in the vicinity of the crater of mont Pelée. On the hill slopes the extensive development of dendritic drainage was very striking. Along the crests of the ridges on the Soufrière the fine dust of the eruptions of May, 1902, was turned into a cement-like mud of considerable tenacity, which retained its place, and was covered over by the heavier material thrown out by the eruptions of September and October, 1902, and March, 1903. In the valleys the permanent and periodical rivers were loaded with the new ash to such an extent as to form viscous streams, which, however, had great powers of erosion on account of the steep slope of the declivities down which they flowed. The bottoms and sides of the gorges were deeply grooved by the sand carried down in this manner by the flowing waters.

During the great eruptions the ejected material was drifted into large beds in the gorges extending radially down the Soufrière. The massing of material was most important in the gorge of the Wallibou river on the west and in that of the Rabaka river on the east side of the island. In these gorges the bed of new material reached a thickness of from 60 to 100 feet. This enormous amount of material was almost entirely washed out of the gorges during the first rainy season following the eruptions of 1902. Not less than 150,000,000 cubic feet of ashes have been washed out of the Wallibou gorge itself, without taking into account the thousands of cubic yards of fresh ash removed from the watershed of the river during the same period. All of this material was, of course, transported directly to the ocean. The shoreline of the mouth of the Wallibou was pushed out not less than 100 yards by the deposition of sediment between May, 1902, and March, 1903. Similar extension of the coastline occurred at the mouth of other rivers along the west side, but in general the shore is too steep along that side of the island for a visible accumulation of debris.

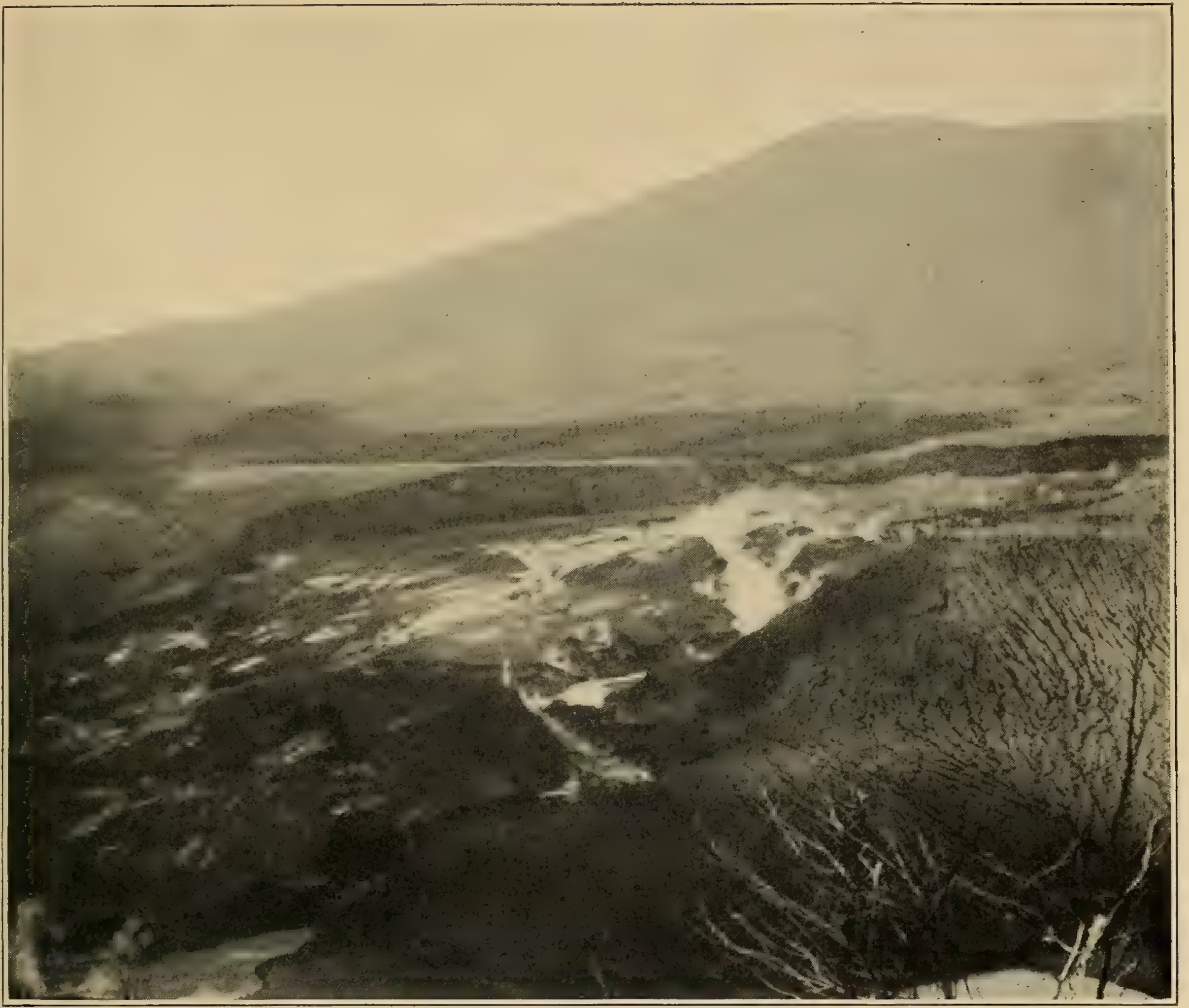

FIGURE 1.—VALLEY OF THE WALLIBOU RIVER, SAINT VINCENT. MAY 30, 1902

Bed of new ash is indicated by the steam rising from it. During the succeeding rainy season almost the whole of this material was removed from the gorge. Dendritic drainage is well indicated in the hill slope at the right.

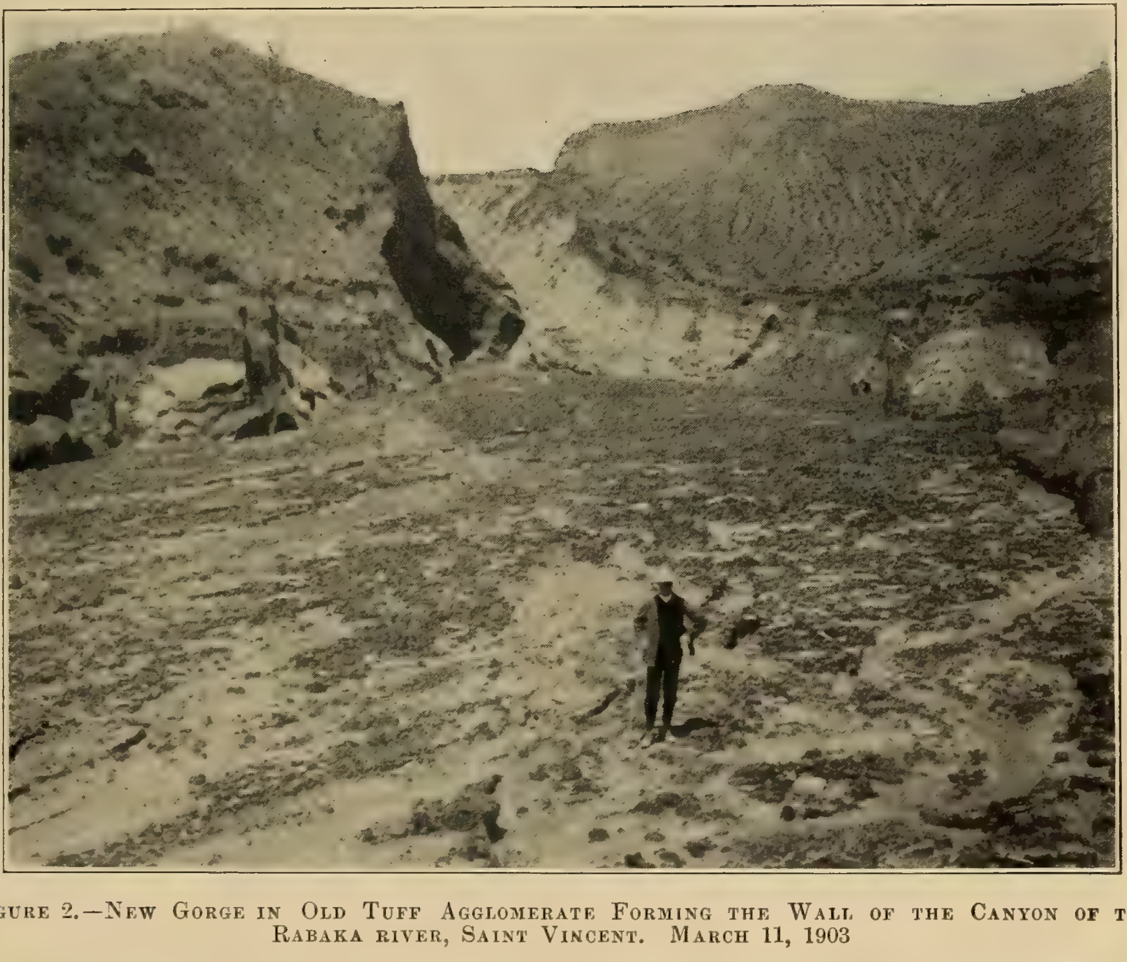

FIGURE 2.—NEW GORGE IN OLD TUFF AGGLOMERATE FORMING THE WALL OF THE CANYON OF THE RABAKA RIVER, SAINT VINCENT. MARCH 11, 1903

Old canyon was filled with ash by eruptions of the Soufrière in May, 1902, and the accumulated waters of a part of the Rabaka drainage basin cut this new gorge 50 feet wide and 100 feet deep. The new ash here contains numberless bombs.

VALLEY OF WALLIBOU RIVER AND NEW GORGE IN OLD TUFF, SAINT VINCENT

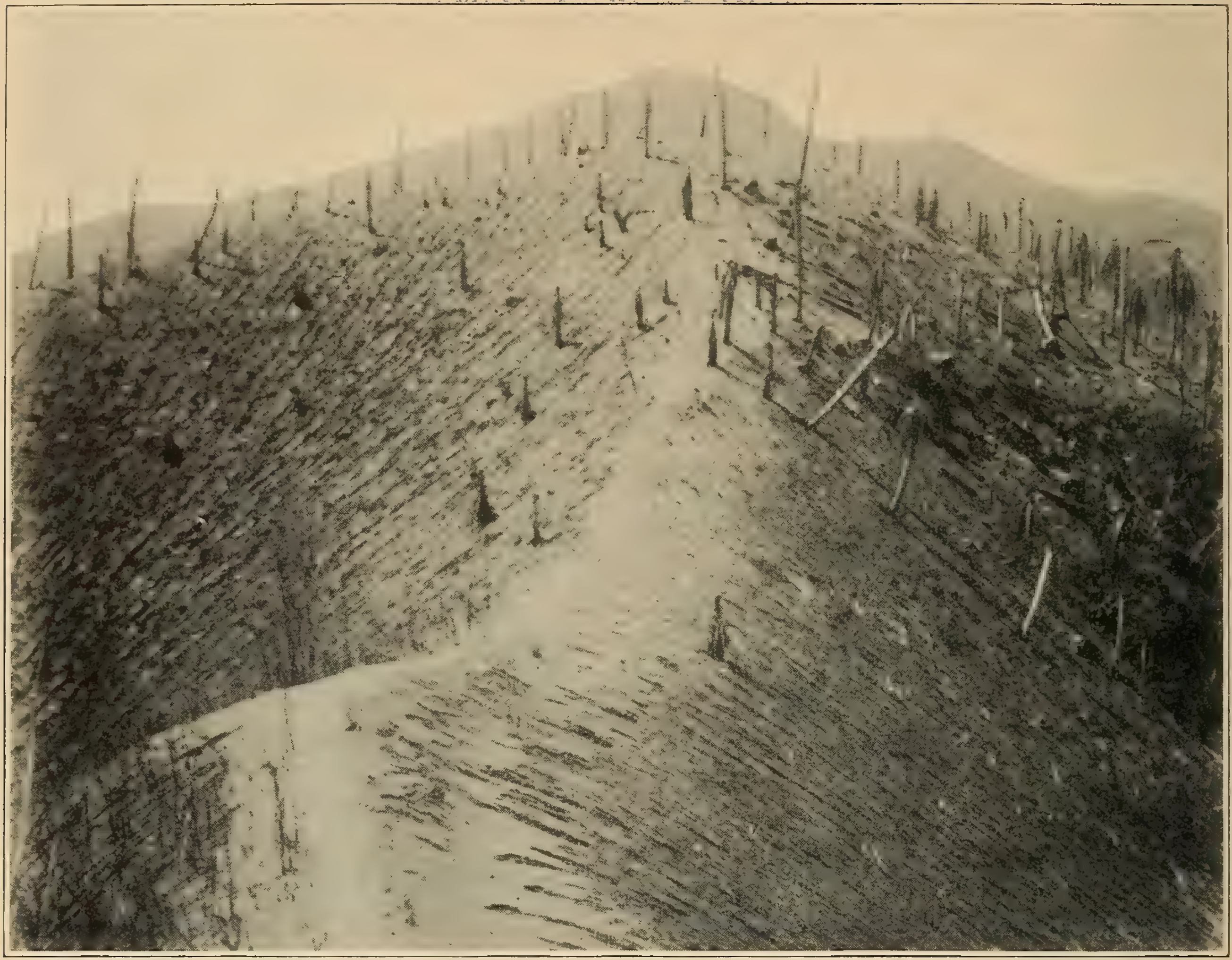

FIGURE 1.—BUNKERS HILL, RICHMOND ESTATE, SAINT VINCENT. MAY 30, 1902

This ridge, near the Wallibou river, shows the dendritic drainage system gradually creeping to crest of the ridge. Material along crest is fine dust, which rains formed into a cement-like coat.

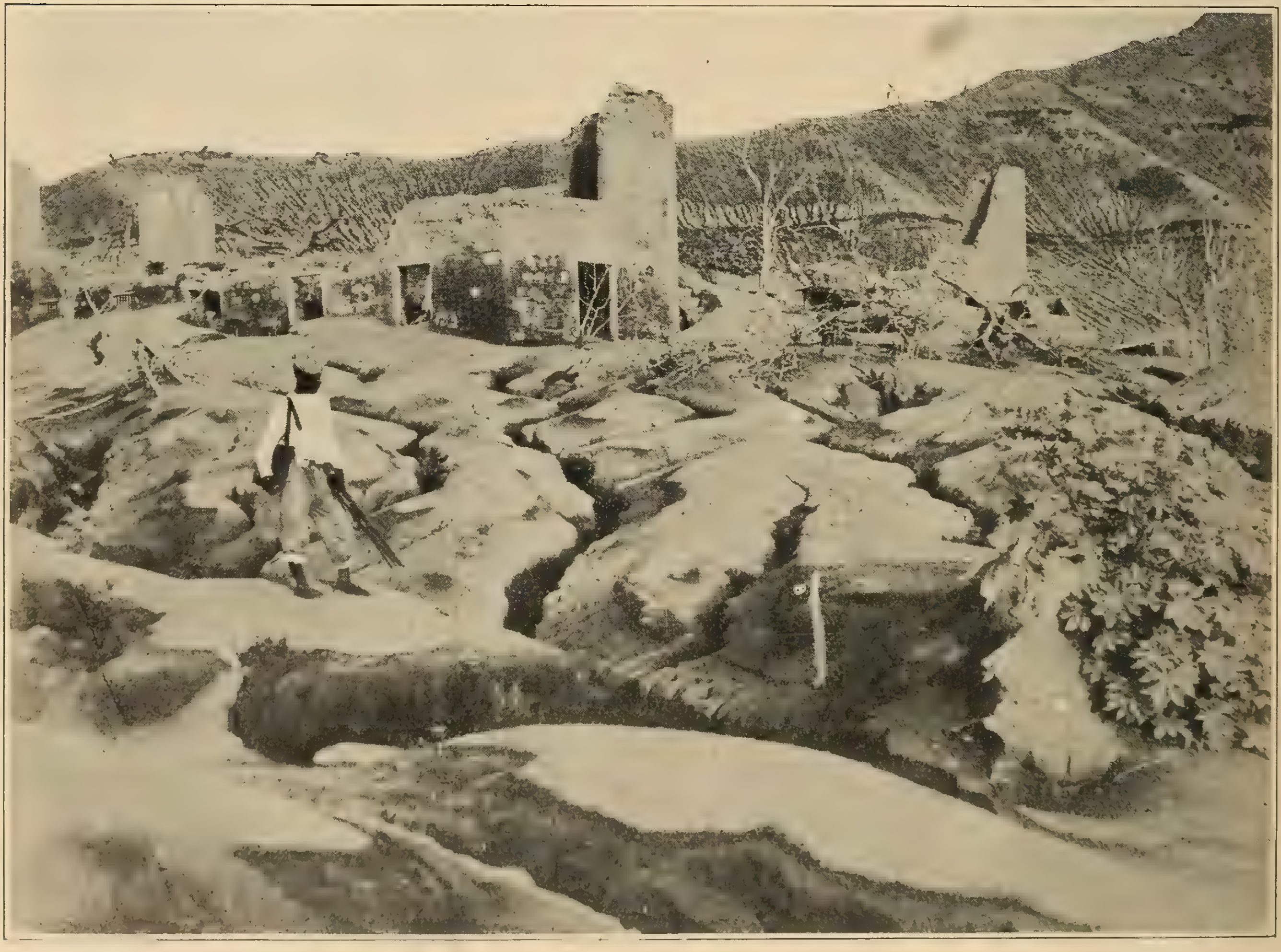

FIGURE 2.—RICHMOND HOUSE, SAINT VINCENT. MARCH 7, 1903

Ridge shown in figure 1 appears in background of this view. New drainage system, due in large part to new surface of the ash, has been carried down into the underlying old tuff without reference to the smaller features of the old drainage. The house was partly destroyed by the hurricane of 1898 and its ruin was completed by the eruption of May 7, 1902.

BUNKERS HILL AND RICHMOND HOUSE, SAINT VINCENT

The vast amount of material carried down by mud flows in the great gorges of the Prêcheur, the Blanche, the Sèche, the Des Pères, and the Roxelane rivers on the west and southwest sides of mont Pelé was likewise lost in the depths of the Caribbean sea without materially affecting the coastline.

On the east side (the windward side) of both islands the shallow waters and the prevailing currents deposited along the beach much of the new ash brought down from the hillsides. The shoreline of Saint Vincent was pushed out from a few yards to 50 or 60 yards for about 7 miles along the eastern coast of the northern half of the island. Along the northern and northeastern coasts of Martinique the effect was even more pronounced, because the mud flows or avalanches there seem to have been more numerous. The extension of the shoreline was greatest at the mouths of the Capot, the Basse Pointe, the Macouba, and the Grand rivers, where it amounted at first to 100 to 200 yards.

The erosive or abrasive work of the volcanic debris transported in the tornadic blasts from the crater was shown on exposed opposing surfaces. Bluffs of this character are more numerous on mont Pelé, and the grooving due to this action were observed along the Des Pères and Sèche rivers and upon Morne Saint Martin, a radial ridge beside the Rivière Blanche, directly in front of the great V-shaped gash in the crater. On the Soufrière some overturned trees were noted, the roots of which were turned toward the crater. These roots were charred and carved by the volcanic sand blast on the sides toward the crater, while the bark on the sides away from the crater was left fresh and uninjured.

GRANDE SOUFRIÈRE OF GUADELOUPE

BY EDMUND OTIS HOVEY

The field evidence indicates that the present active cone of this volcano is closely analogous to the new cone and spine of mont Pelé, Martinique—that is to say, it has been pushed up bodily as a rigid mass into its present position or has welled up through the conduit of the volcano in such a viscous condition that contact with the atmosphere rendered it too rigid to form a flow, probably the latter.

At the base of the cone, on the north, there is a gently rising plateau, apparently a segment of a circle, which indicates the position of a part of the rim of a crater in existence before the construction of the present cone. The remainder of the old crater rim, if such this was, has been entirely covered by the present cone. The top of the cone shows several jagged masses of solid lava rising to heights of 40 to 100 feet above the general level. There is no true crater or anything resembling a crater in the cone. The cone, however, is traversed by a system of clefts or fissures, which are best developed along two main directions, crossing at an oblique angle like a gigantic letter "X." The present vents of steam and sulphurous gases lie in the great fissures, with the exception of the vent known as "Napoleon," which is about 75 feet from one of the large fissures in a minor transverse fissure.

From the sea the profile of the mountain leads one to infer that the present active cone lies within a ruined crater 2½ miles or more in diameter. From the summit of the mountain, however, this impression is dissipated by the relations of the surrounding peaks and the peculiarities of the erosion forms, and the independence of the Grande Soufrière as a volcanic center seems the more probable view.

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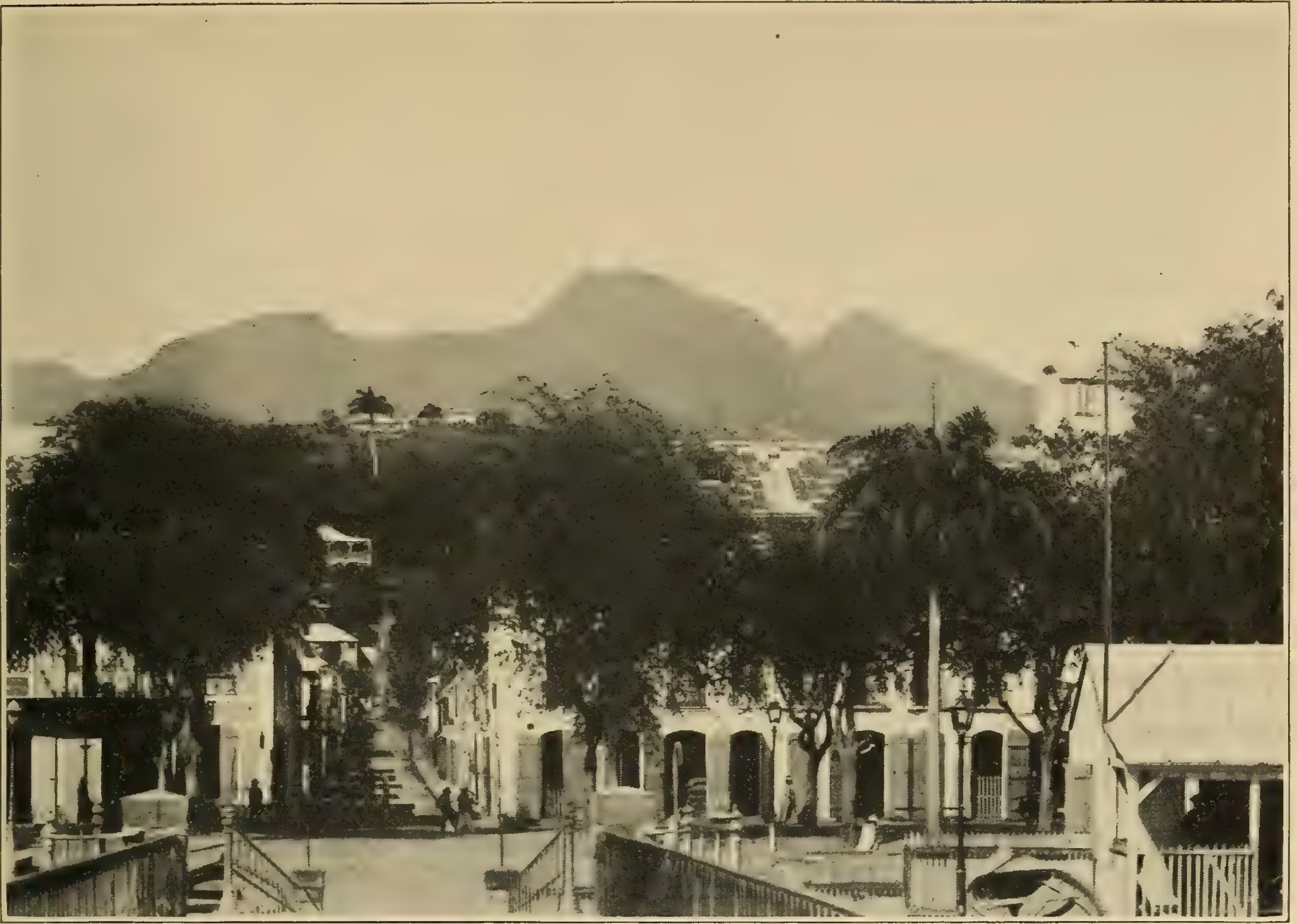

FIGURE 1.—GRANDE SOUFRIÈRE OF GUADELOUPE FROM BASSE TERRE. APRIL, 1903.

Peak at right is Morne l'Échelle, the middle peak is the Soufrière, and the left one is Nez Cassé.

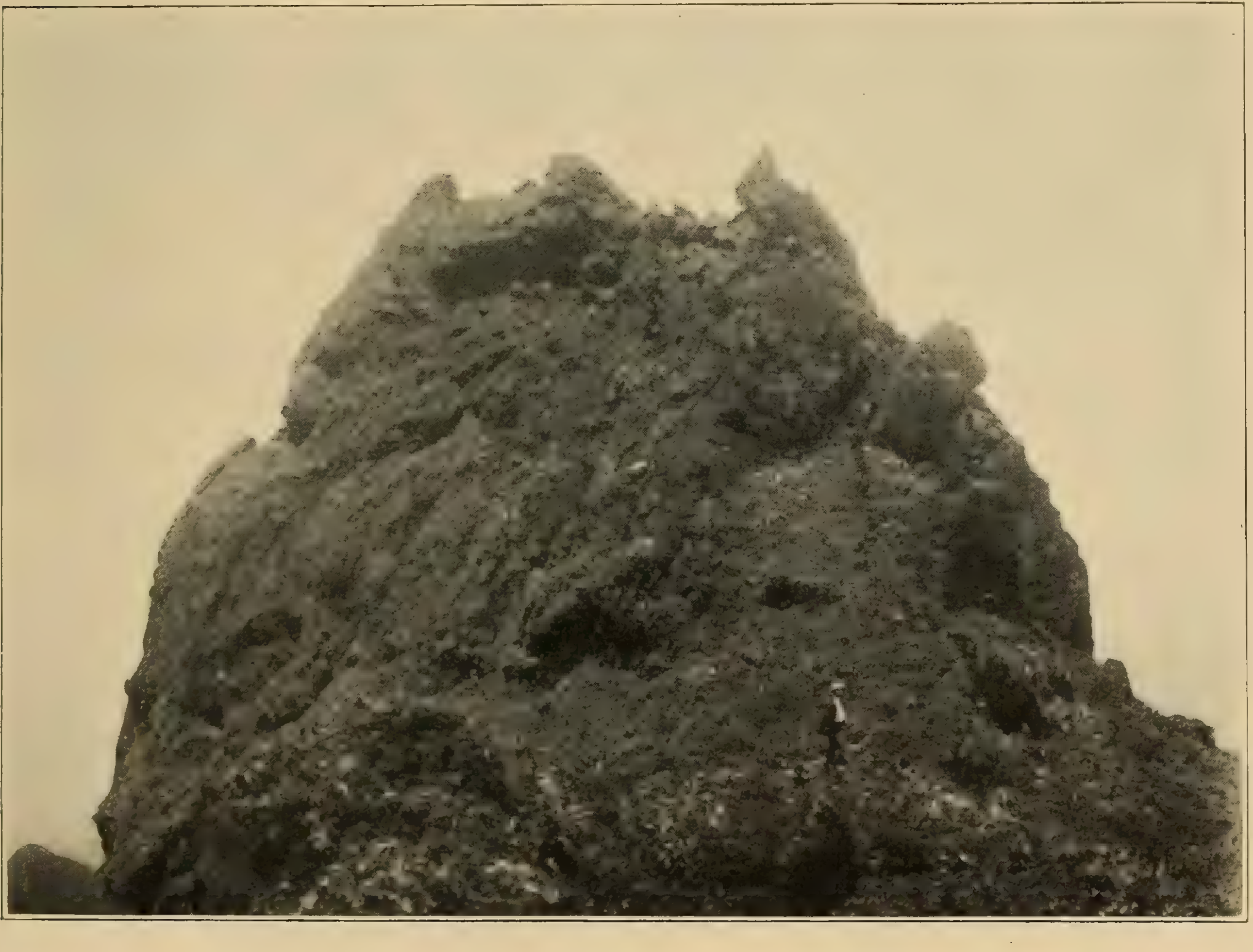

FIGURE 2.—PITOU DU SUD, ON THE SUMMIT PLATEAU OF THE SOUFRIÈRE. APRIL 17, 1903

One of the pinnacles of solid rock which seem to indicate the relationship between this cone and the new cone of mont Pelé.

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WINCHELL, N. H. Peléliths. *Am. Geol.*, vol. xxxiii, pp. 319–325, May, 1904.

It was announced that, in accordance with the printed program as arranged by the Council, no afternoon session would be held, but the Society would accept the invitation of the managers of the Louisiana Purchase Exposition extended to the American Association for the Advancement of Science and the affiliated societies to visit the grounds and buildings.

The Society then adjourned.

SESSION OF FRIDAY, JANUARY 1

The Society convened at 10 a m, President Emmons in the chair.

No administrative business was presented.

The first paper presented was

DOMES AND DOME STRUCTURE OF THE HIGH SIERRA

BY G. K. GILBERT

The paper was discussed by A. P. Coleman, C. W. Hall, I. C. White, and C. W. Hayes. It is published as pages 29–36 of this volume.

The next three papers were read by title:

TRENT RIVER SYSTEM AND SAINT LAWRENCE OUTLET

BY ALFRED W. G. WILSON

This paper is printed as pages 211–242 of this volume.

POST-GLACIAL CHANGES OF ATTITUDE IN THE ITALIAN AND SWISS LAKES

BY FRANK B. TAYLOR

The paper is printed as pages 369–378 of this volume.

BASIN OF THE PO RIVER

BY GEORGE L. COLLIE

[*Abstract*]

The paper is the result of field work done on the Po plain in the spring of 1903. The basin of the Po was an arm of the sea during the Miocene; a portion of the

time probably a strait connecting the Adriatic with the Mediterranean through the present Col d'Altare. The sea was gradually crowded out by the encroachment of sediments, brought in from the Alps to the north and from the Apennines to the south. Sediments from Alpine sources are coarse; from Apennine sources, fine. The total area of the basin is 27,000 square miles, of which 16,000 square miles are mountainous and 11,000 square miles belong to the plain of the Po.

Borings in the plain show that it is composed of a series of approximately horizontal sands, clays, and marsh deposits, the latter including lignitiferous clays. The sands contain marine shells, the clays carry land shells. The whole succession indicates alternation of marine, fresh water, and land conditions. The thickness of the deposits ranges from 572 to 695 feet.

There is little fine alluvium in the upper Po, the river flowing over coarse deposits; but below the Sisera river alluvium of a fine type is common.

The upper Po is everywhere crowded close to the northern spur of the Apennines, forced over apparently by the large and heavily laden tributaries from the Alps. In times of flood the river carries an immense amount of debris, estimated to be $\frac{1}{300}$ of its volume. In spite of this heavy load, the river is not aggrading its bed to an appreciable extent.

This non-aggradation is due in large measure to the lake system of northern Italy, which drains into the Po and supplies it with $\frac{4}{10}$ of its water content. During periods of high water, in the fall and spring, the sediment-laden streams from the Alps bring their load to the Po and deposit it. The lakes, however, being basins of reception, not only take out the sediments from the drainage, but also store the water and supply it more gradually than do the lakeless streams. Lago di Garda in time of great rainfall scarcely changes its level; the smaller lakes, such as Como or Maggiore, show great changes of level within a few hours, but on the whole they all tend to restrain the water. The result is that after the debris-laden streams have deposited their sediments in the Po and temporarily raised its bed later there comes a volume of comparatively clear water, which removes the previous accumulations and an equilibrium is maintained on the whole.

The Po is thoroughly diked from Cremona to the marshes of the delta. It is customary to place the froldo or main dikes at some distance from the river, thus allowing the river to overflow the intermediate flood plain or golene for some distance before reaching the dikes. The golene are frequently covered with willows and thick underbrush and the velocity of the current is greatly reduced thereby and there is little active erosion upon the dike itself. The dikes are continually being extended; the extension of dikes accounts in a measure for the rapid extension of the delta in modern times. Between 1200 and 1600 A. D. the delta advanced on the average about 70 feet annually; for the last few decades, its advance has been at the rate of about 200 feet annually.

The flood-plain deposits of the upper Po are cross-bedded and very irregular; the beds are chiefly cobbles, coarse gravel, and pebbles; occasionally wedges of sand are thrust in, the latter of limited extent.

The beds show great variations in size of materials; there are sudden changes from coarse to fine gravel and *vice versa*. The beds are not continuous over wide areas; generally there is a change in composition and texture every few rods. Occasionally there are local deposits of silt and clay, stratified as a rule, which cover a few acres. One of these deposits in the environs of Turin covers 40 acres.

On the lower Po the flood-plain deposits are much finer in texture and show more regular arrangement than those quoted above. Much of the material is silty clay and fine sand. Laminated structure is common, the thin laminæ extending for several hundred feet, but invariably replaced sooner or later by sediments of different texture or composition. When long sections are exposed so that they can be seen ensemble, it is noticeable that the beds undulate. Strictly speaking, there is no horizontality of beds, but rather a slow rise and fall. Long, flat augen of sand are the apparent cause of this arrangement. These flat lenses occur frequently, the finer sediments wrap them about, and the bedding of the latter is made to show corresponding undulations. The degree of undulation is determined by the thickness and length of the sand lenses.

The next paper presented was

NANTUCKET SHORELINES, II

BY F. P. GULLIVER

The paper is printed as pages 507–522 of this volume.

The next paper was read by the Secretary, entitled

GEOLOGY UNDER THE PLANETESIMAL HYPOTHESIS OF EARTH-ORIGIN

BY HERMAN L. FAIRCHILD

Remarks were made by C. W. Hayes, W. M. Davis, and G. K. Gilbert. On motion of C. W. Hayes, seconded by G. K. Gilbert, it was voted that the Council be requested to consider the desirability of publishing a preliminary edition of the paper and inviting written discussion by the Fellows of the Society, the communications to be edited and published in the final edition.

On motion of W. M. Davis, it was voted to authorize the expenditure of sufficient money to print an extra edition for wide distribution to teachers of earth-science.

The paper and discussion are printed as pages 243–266 of this volume.

The next paper was presented in abstract by G. K. Gilbert, by permissive vote of the Society, the author being absent.

BASIN RANGE STRUCTURE OF THE HUMBOLDT REGION

BY GEORGE D. LOUDERBACK

Remarks were made by W. M. Davis. The paper is printed as pages 289–346 of this volume.

The following paper was read by title:

GLACIAL EROSION IN THE FINGER LAKE REGION OF NEW YORK

BY M. R. CAMPBELL

The next paper was read by title:

CARBONIFEROUS OF THE APPALACHIAN BASIN

BY JOHN J. STEVENSON

The paper is printed as pages 37–210 of this volume.

The following paper was presented:

FURTHER STUDIES OF OZARK STRATIGRAPHY

BY C. F. MARBUT

The Society adjourned for the noon recess and lunch, and on reassembling the first paper presented was:

DEPOSITION OF THE APPALACHIAN POTTSVILLE

BY DAVID WHITE

Remarks on the subject of the paper were made by I. C. White. The paper is printed as pages 267–282 of this volume.

The second paper was:

BENTON FORMATION IN EASTERN SOUTH DAKOTA *

BY J. E. TODD

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Occurrence in adjacent states	574

INTRODUCTORY

In the recent study of the geology of South Dakota by the members of the United States Geological Survey diverse interpretations have appeared. Mr Darton's studies about the Black hills showed there 1,450 to 1,700 feet of Benton strata, while near Sioux City it had been counted 80 feet or less, and around Mitchell, where a sandstone which had been counted Dakota appears, it seemed virtually absent. Moreover, at the west the formation shows a threefold character, as follows:

	Feet
3. Carlile formation. Gray shales, with thin sandstones, limestones, and concretionary layers	500–750
2. Greenhorn limestone. Impure, slabby limestone	50
1. Graneros shale. Dark shale, with layers of massive sandstone in lower part in places.	900

In the east, however, only shaly clay had been recognized. This was the more remarkable, because the Greenhorn limestone described by Gilbert from Colorado, and widely known in the Rocky Mountain region as the "Oyster-shell rim," would from its fauna be specially likely to appear also along the shallow eastern margin of the Cretaceous ocean.

A suspicion that there was something wrong was further impressed by the finding of *Prionocyclas wyomingensis*,* a Benton fossil, above the so-called Niobrara, near Hawarden, Iowa, and also by the discovery of marine fossils far below the top of the supposed Dakota, near Woonsocket, South Dakota.

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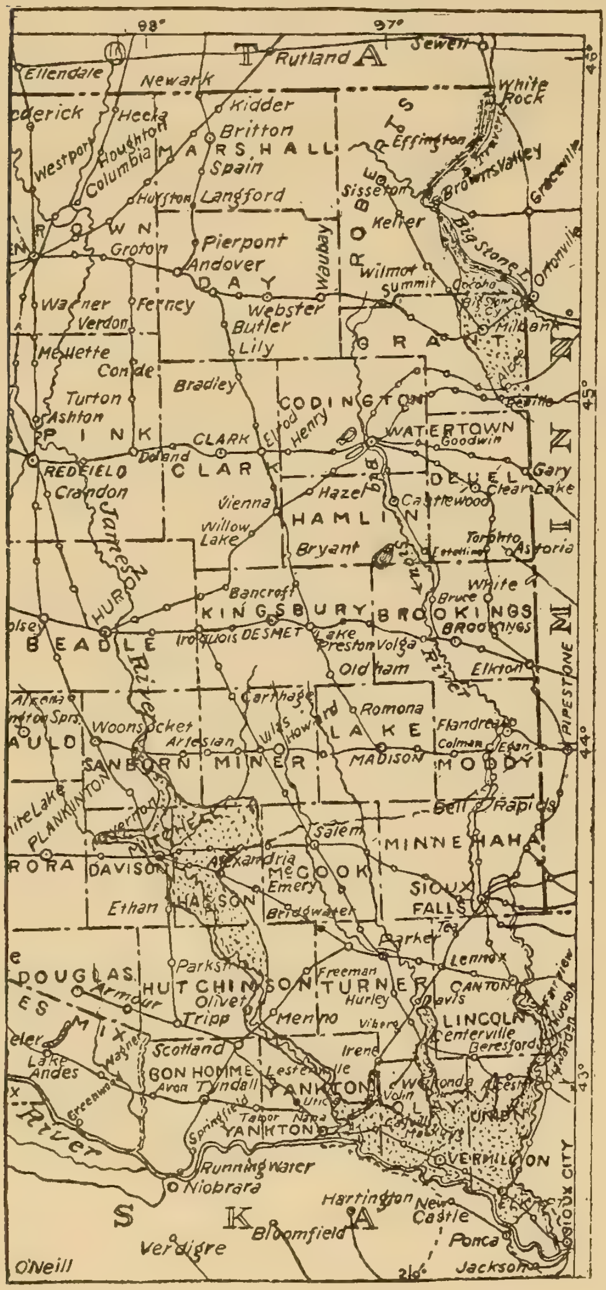
* Printed by permission of the Director of the U. S. Geological Survey.

Original Missouri River Section Reexamined

The writer has repeatedly visited scattered exposures along the Missouri river and has hitherto accepted without much question the interpretations of Meek and Hayden, who first classified the Cretaceous rocks of the region and named them. He had extended those interpretations to areas in the James River valley, which he has studied more carefully.

Last July, at the request of Mr Darton, he spent several days in company with Mr G. E. Condra, of Nebraska University, in making a comprehensive review of the section along the Missouri river from near Homer, Nebraska, to the mouth of the Bow river, in Cedar county, Nebraska. We found the only difficulty. and that not a great one, near the old site of Ionia, in Dixon county. There the chalky limestone, which is prominent on the top of the bluffs near Ponca, steals beneath the river in a talused bluff; so that, like others, we at first overlooked it and had to return to discover what had become of it. Its top was nearly hidden at the water's edge at the Ionia ferry. With this exception the whole section seemed clear, the only uncertainty being in the thickness of the formation, which appears to increase irregularly toward the northwest.

Besides this the writer has since reconnoitered the Minnesota valley from Marshall, Minnesota, to Sisseton, South Dakota, and studied with some care all the Cretaceous exposures along the Missouri and Big Sioux rivers and Brule creek in the Elk Point quadrangle.


98°
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White Rock
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Westport
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M A R S H A L L
Spain
Effington
Browns Valley
Graceville
Sisseton
Hurston
Langford
W N
Groton
Pierpont
Andover
Keller
Big Stone L.
Ortonville
Waubay
R O B
Wilmot
Summit
D A Y
Webster
Butler
Lily
Warner
Ferney
Verdon
Milbank
G R A N T
Mellette
Conde
Bradley
Turton
Ashton
C O D I N G T O N
P I N K
Elrod
Henry
CLARK
WATERTOWN
Goodwin
45°
Doland
REDFIELD
C L A R K
Crandon
D E U E L
Gary
Clear Lake
Hazel
Castlewood
Vienna
James
Big Sioux
H A M L I N
Willow Lake
Bryant
Toronto
Astoria
White
Bruce
Bancroft
HURON
K I N G S B U R Y
B R O O K I N G S
BROOKINGS
B E A D L E
Iroquois
DESMET
Lake Preston
Volga
River
Oldham
Elkton
PIPESTONE
Carthage
Romona
Flandreau
Woonsocket
Artesian
Howard
L A K E
Colman
Egan
44°
SANBORN
M I N E R
MADISON
M O O D Y
White Lake
PLANKINTON
Bell
Rapids
Salem
M I N N E H A H A
DAVISON
Alexandria
McC O O K
Emery
SIOUX FALLS
Ethan
HANSON
Bridgewater
Tea
Parker
Parkston
Lennox
DOUGLAS
Armour
HUTCHINSON
Freeman
T U R N E R
CANTON
Olivet
Hurley
Davis
Tripp
Menno
Viborg
LINCOLN
Centerville
Beresford
Hudson
M I X
Scotland
Irene
Hawarden
Lake Andes
Wagner
BON HOMME
Lesterville
Avon
Tyndall
YANKTON
Wakonda
43°
Greenwood
River
Springfield
Tabor
YANKTON
VERMILLION
Running Water
Niobrara
SIOUX CITY
Hartington
New Castle
S
K
A
Bloomfield
Ponca
Verdigre
O'Neill
Jackson
M
I
N

FIGURE 1.—*Extent of Benton under Drift in eastern South Dakota.*

We will first give our results concerning the general section, then compare it with the interpretations of previous students of the region, and afterward give the distribution of the Benton throughout the eastern part of South Dakota.

Results

A. The three members of the Benton found along the Rocky mountains appear also on the Missouri river, as the following combined section shows.

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*Iowa Geol. Survey, vol. 10, p. 114, 1899.

The top of the Benton shale ends abruptly and evenly against the Niobrara chalk, which is quite hard and massive below.

	Thickness.	Depth.
Carlile :		
Blue shaly clay, with selenite crystals	32	32
Blue shaly clay, with a zone of smaller lenticular calcareous concretions above and of larger ones below	8	40
Blue shaly clay, with some concretions showing Prionocyclus, *Ostrea congesta, Inoceramus deformis* (?), Serpula, Pinna, etcetera, grading into next	125 ±	165 ±
Greenhorn :		
Blue chalk, weathering white, *I. labiatus*, shading into next	4	169
Hard slaty blue limestone, sometimes hard calcareous shale or slabby limestone, with many *I. labiatus*, shading into next	12	181
Blue chalk, with some *I. labiatus*, shading into next	12	193
Graneros :		
Darker shaly clay	30–50	243
Black carbonaceous shale, inconstant	2	245
Sandy shale and clay, interstratified in thin layers	13	258
Dakota (?) :		
Soft massive yellow sandstone, with many root marks above	7	265

The irregular thickening toward the north is shown on the Big Sioux as well as along the Missouri.

From our own observations and those of other students of this field we may generalize as follows :

	Feet.
3. Carlile shales. Gray shales and shaly clays, with several zones of ferruginous and calcareous, lenticular concretions, and occasional thin limestone layers, with *Prionocyclus woolgari*, a few small oysters, probably *O. congesta*, but rarely showing deep valve, *Inoceramus deformis*, sometimes 15 inches across; Serpula and Pinna skeletons of large saurians near the top. A quite extensive rusty irregularly bedded sandstone, 10 to 50 feet thick, appears in the upper portion from the vicinity of Mitchell westward	140–175
2. Greenhorn limestone. Thin bedded or slabby bluish chalky limestone, shading above and below, through 5 to 10 feet of bluish chalk, into shale, the whole weathering white or cream color, and abounding in *Inoceramus labitus* and the scales and teeth of fishes, but small oysters rare and not showing much age. The whole formation quite persistent, though apparently thinning to the north and west	30–45
1. Graneros shales. Dark pyritiferous and carbonaceous shaly clays, often plastic, more sandy below, sometimes developing into rusty sandstone strata	45–100

The limit between this and the Dakota is quite uncertain, for not only are there inconstant sandstone layers, sometimes several feet in thickness in the lower part of the Benton, but the upper part of the Dakota is much occupied by strata of clay shale of variable thickness.

B. The thickness of the Benton is much greater in this region than has hitherto been reported. This increase along the Missouri has been made by addition of the Greenhorn, which had been called Niobrara, and the overlying Carlile, and on the James by the inclusion of the sandstone formerly called the Dakota.

Hayden gave 50–100 feet as its thickness near Sioux City,* and 150–200 its maximum † for the region.

Meek with greater care says that "along the Missouri in Nebraska, below the Great Bend, it probably does not attain a thickness of more than 100 feet." ‡

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* Final Report of Nebraska, p. 42, 1872.

† Second Ann. Report U. S. Geol. Survey of Terr., p. 90, 1870.

‡ Hayden's Final Report, vol. ix, p. xxx, 1876.

Calvin at one time gave it as 40 feet,* but later gave it greater.† Bain, with Calvin's earlier view, made it 50 feet.‡

White and Saint John wisely refrained from adopting Hayden's names and so avoided the error.§

C. The Greenhorn limestone is closely equivalent to the Inoceramus beds of White, and has been unfortunately confused with the Niobrara from the first. This limestone and its associated chalk abound in *Inoceramus labiatus*, which fossil occurs in the Graneros, but in the Carlisle and Niobrara gives place to *I. deformis.* (*?*)

D. The dip of the formation is generally slight and toward the north. Observations of the top of the Benton show it to be about 1,380 in northern Union county, South Dakota, and 1,300 about Mitchell; but there is also a dip eastward with the general slope of the country, so that about Marshall, Minnesota, it is about 1,100. Near Milbank it is about 1,100, but at White Rock, near the north end of lake Traverse, it is considerably lower.

CORRECTION OF FORMER INTERPRETATIONS

1. The main error, *videlicet*, mistaking the Greenhorn chalky limestone for the Niobrara, was first made by Hayden and Meek, and later students simply accepted and continued it. This is evident from the following quotations:

Doctor Hayden says the Dakota "is succeeded by a series of black, plastic, laminated clays, with light-colored arenaceous partings and thin layers of sandstone. Near the mouth of the Vermilion river the upper portion becomes more calcareous and gradually passes into the next group."‖

He also says, in the table which has been so much copied, that the Niobrara "ranges in bluffs along the Missouri below the Great Bend to the vicinity of the Big Sioux river; also below there on the tops of the hills."¶ And more definitely in 1872, that the Niobrara, "chiefly limestone, almost entirely composed of the shells of a species of Inoceramus," appears in the hills near the north limit of the Omaha reservation.**

Meek, who first outlined the present classification of Cretaceous rocks of this region in 1856,†† continues this view in Hayden's Final Report, volume ix, page xxv.

White and Saint John, as already stated, avoided the error by not adopting Hayden's names,‡‡ but Calvin attempted a harmony and fully accepted the mistake, and, moreover, adopts it as a basis for a theory concerning the origin of Cretaceous formations.§§ He, however, acknowledged his error after finding Prionocyclas in the shales above his supposed Niobrara. Bain,‖‖ and also the writer, followed the same error for a time.

2. Another error followed logically from the first, *videlicet*, that there is a syncline

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* Iowa Geol. Survey, vol. i, 128.

† Ibid., vol. x, p. 114.

‡ Ibid., vol. iii, p. 110, 1893.

§ Geol. of Iowa, vol. 2.

‖ Second Ann. Report U. S. Geol. Survey of Terr., 1870, p. 90.

¶ Proc. Acad. Nat. Sci., Phila., 1861.

** Final Report on Nebraska, 1872, p. 42.

†† Am. Acad. Arts and Sci., Boston, vol. v, p. 405.

‡‡ Geol. of Iowa, vol. i, p. 274, 1870.

§§ Am. Geologist, vol. ix, p. 304, quoted largely; Iowa Geol. Survey, vol. i, p. 129, 1892.

‖‖ Iowa Geol. Survey, vol. v, p. 275; also vol. viii, p. 331.

connecting the Inoceramus limestone with the Niobrara. This would virtually follow from Hayden's interpretation, though he did not announce it. Bain distinctly formulated it in his Iowa report.*

3. Another mistake arose from the difference in composition of the Benton in different localities. A rusty sandstone is found in the James River valley, sometimes 30 feet or more in thickness. It has much of the aspect of the Dakota. Where first met with it was separated from the Niobrara chalk by about 50 feet of clay, about the thickness of the Benton near Sioux City, according to the then accepted interpretation. It was considered Dakota and was so published in Water Supply and Irrigation Paper number 34, and was so printed on the geologic maps of the Olivet and Mitchell folios; but further investigation showed that farther north the clay nearly disappeared and the sandstone was brought up closely to the Niobrara chalk and often in such a way as to suggest unconformity. Furthermore, distinctly marine shells like the Benton were found 250 feet or more below the Niobrara chalk and 100 feet above the main artesian flow from the Dakota. In short, the fossil horizon corresponds fairly well to the Greenhorn limestone. Moreover, the sandstone seems to be limited on the south and probably on the north, but extends far west. This appears chiefly from the distribution of soft-water wells, which are known to be supplied from this horizon. That it extends westward at least as far as the Black hills is attested by the copious water and its increase of pressure toward the west, as in the Dakota strata lower down.

In fact, the existence of thick masses of shale between it and the main water-bearing sandstone which all recognize as Dakota, together with the inconsistency of having the Benton virtually absent so near to the thick beds of it around the Black hills, forms alone a strong reason for revising the earlier opinion.

Harmonious with the modified view is the occurrence in the same region of a meager water horizon between the two, which not improbably corresponds to the Greenhorn horizon. That formation is known to be water bearing where it has been weathered, as is attested by copious springs along the Big Sioux. Probably its porosity is less where not weathered, though it may still convey a perceptible amount of water.

Its geographical Extent

The Benton extends therefore up the Missouri as far as Yankton, and without doubt lies immediately below the drift up the James with considerable width as far as the north line of Davison county, up Enemy creek to a point south of Mitchell, and up the Firesteel to a point north of Mount Vernon. It extends up the Vermilion between cliffs of chalkstone, all buried in till, probably to Centerville; up Brule creek, exposed in patches from Richland into the southwest corner of township 94 north, range 50 west, and under the drift possibly to the north line of Union county. Along the Big Sioux it appears here and there nearly to Canton.

The top of the Greenhorn limestone disappears below the Missouri at Ionia Ferry landing, altitude 1,115 feet above tide, and below the Big Sioux, on section 4, township 94 north, range 48 west, 1,150 feet above tide, and below Brule creek, section 7, township 92 north, range 49 west, 1,140 feet above tide.

The Carlile shales, weathered to a waxy gritless clay, are frequently exposed along smaller streams. Between the two latter streams the Niobrara is struck in wells near Nora post-office, in the southeast corner of township 94 north, range 50 west, where the top of the Benton is found to be about 1,380 feet above tide.

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*Iowa Geol. Survey, vol. iii, p. 103, 1893; and vol. viii, p. 329.

Another area of Benton immediately below the drift has been quite confidently determined in the Minnesota valley. Minnesota geologists had inferred from numerous Pierre fossils found in Lyon county, Minnesota, that the formation underlying the drift there is Pierre. This inference was extended to the region around Big Stone lake, partly because no flow was obtained from a deep boring at Milbank, South Dakota.

More careful inquiry the past season developed the following facts:

1. Chalk of bluish white tint and containing angular fragments of Inoceramus shells like the Niobrara was struck in wells in a strip extending from section 2, township 118 north, range 48 west, 10 to 12 miles in a northwest direction. It was reached at from 50 to 80 feet depth, and in some cases was found to be 20 to 25 feet thick. Its altitude is about 1,100 feet above tide.

2. At Milbank, in several wells, shells of Prionocyclus were found at a depth of about 40 feet from the surface in black clay. One examined was about 10 inches across and in a concretion which showed no abrasion. It is probable that the clay was preglacially disintegrated from Benton shale.

3. In the deep well at Milbank a strata of copious soft water was struck at about 300 feet, which rose to 20 feet of the surface. Apparently the same was struck at 200 feet, 1 mile south, and a few miles southwest flows of similar water are obtained from about 400 feet, all probably from the Dakota.

4. No exposures of shale were found on Big Stone lake, except on the Minnesota side near the north end, where there is a slope of bare lead-colored shale with biscuit-shaped ferruginous concretions with cracked interior. It shows 25 feet above the water and appears to be part of a slide from 20 feet higher. No fossils were found. Similar clays have been observed farther north.*

5. At White Rock, in the extreme northeast corner of South Dakota, according to Morley and Steinmest, well drillers, blue chalk 20 feet thick was struck at a depth of 300 feet. If this is Niobrara it would indicate quite a drop from near Revillo. That fact, with its thickness corresponding to that of the Greenhorn, makes it seem likely it is the latter.

Hence we may reasonably infer that the Benton underlies the drift in that region east of a line running north and south a few miles west of Milbank and curving south and east past Revillo. The limit extends north near Browns valley. The eastern limit is probably bounded on the east by granite knobs like those exposed from Bigstone lake to Granite falls.

Occurrence in adjacent States

In Minnesota, Benton fossils have been found in the shale at Sauk rapids. In Lyon county the Pierre fossils reported by the Minnesota survey were certainly from the Pleistocene till in some cases, and probably in all, and not far away copious soft water obtained from 250 feet rises within 20 feet of the surface, and strong flows come from 350 to 400 feet. If the Benton has its usual thickness there, it doubtless lies just below the till.

In Iowa, along the Big Sioux, the Greenhorn forms a marked terrace of erosion as far north as Akron. The Carlile clay is deeply developed above it at Hawarden, and is 60 to 75 feet thick as far south as east of Elk point.

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* Minn. Geol. Survey, vol. i, p. 619.

In Nebraska the chalk below Ponca, which has been called Niobrara, is all Greenhorn, including that west of Homer and Dakota City. The writer is sure, also, from personal knowledge that that exposed near Milford on the Big Blue, and probably that near Valparaiso, in Saunders county, is the same.

The Niobrara is known to extend nearly to New Castle, Cedar county, and probably its eastern margin (the western of the Benton exposures) extends thence south and southwest.

The third paper was

IROQUOIS BEACH IN ONTARIO

BY A. P. COLEMAN

Remarks were made by G. K. Gilbert, Robert Bell, H. L. Fairchild, W. M. Davis, and the author. The paper is printed as pages 347–368 of this volume.

The fourth paper was

EVIDENCES OF SLIGHT GLACIAL EROSION IN WESTERN NEW YORK

BY H. L. FAIRCHILD

This paper will be printed in volume 16 under a different title.

The next paper was by the same author:

WANING OF THE GLACIERS OF THE ALPS

BY H. L. FAIRCHILD

The presentation was in description of lantern views from photographs taken during the preceding summer which illustrated the decrease of Alpine glaciers in recent years.

The following paper was presented:

EVIDENCE OF THE AGENCY OF WATER IN THE DISTRIBUTION OF THE LOESS IN THE MISSOURI VALLEY

BY G. FREDERICK WRIGHT

[*Abstract*]

The paper is the result of field work conducted during the past year in the vicinity of the Missouri between Saint Joseph and Saint Louis. The direct evidence of the agency of water in distributing the loess is found: (1) In the relations of the loess to the main valleys of ths Missouri and its larger tributaries; (2) the existence of distinct laminæ, at a height of 180 feet above the river at Saint Joseph, which are very clearly of water origin; (3) the new light shed upon the glacial occupation of the region by the discovery of northern drift on the south side of the Missouri river 40 miles beyond the boundary which has heretofore been assigned to it; (4) considerations which show the doubtful character of the conclusions drawn from the fossil shells found in the loess; (5) calculations showing the reasonableness of the supposition that at the close of the Iowan stage of the glacial period there were

periodical floods each summer sufficient to cover the whole region occupied by the great body of the loess and the presentation of a theory that would seem to harmonize all the facts.

Remarks were made by B. Shimek, J. E. Todd, and the author. The paper is published in the American Geologist, volume xxxiii, 1904, pages 205–222.

The last paper presented was the following:

FRESH-WATER SHELLS IN THE LOESS

BY B. SHIMEK *

[*Abstract*]

1. A review of the available literature in which reference is made to the occurrence of fresh-water shells in the American loess, with a discussion of the significance and weight of such testimony, showing that as yet no well-authenticated cases of the occurrence of fluviatile shells, at least in original loess, are known.

2. A statement of the author's own experience in the study of loess mollusks, which shows that land shells greatly predominate, and that only such fresh-water forms as inhabit temporary small ponds and streamlets occur in the loess, and these in relatively small numbers.

In discussion remarks were made by G. F. Wright, Robert Bell, J. E. Todd, and the author.

The remaining papers of the program were read by title, as follows:

COMPARISON OF THE STRATIGRAPHY OF THE BLACK HILLS, BIGHORN MOUNTAINS, AND ROCKY MOUNTAIN FRONT RANGE

BY N. H. DARTON

The paper is printed as pages 379–448 of this volume.

NOTES ON THE GEOLOGY OF THE HELLGATE AND BIG BLACKFOOT VALLEYS, MONTANA

BY N. H. WINCHELL

[*Abstract*]

The following is a provisional general section of the rocks of the region in descending order:

1. The early Pleistocene is recorded in the most of the region only by the valleys eroded and by the terraces along the valleys, but in the region of Placid lake is a sheet of recent glacial deposits. This drift evidently was brought from the north by glaciers that occupied the valley between the Mission range and the Rocky Mountain range.

2. Calcareous tufa, containing chert and fossil leaves. At numerous places tufa of this kind is found, and sometimes it is very thick and massive. The flint nodules have been used by the aborigines in making their implements.

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*Introduced by S. Calvin.

3. The Tertiary is identified only in the valley of the Hellgate near Missoula and doubtfully in township 10 north, range 11 west.

4. A calcareous phase of the Cretaceous supposed to belong to the Niobrara, carrying Inoceramus and Ostrea.

5. Green shale of the Cretaceous appears to be several hundred feet thick.

6. Gray, shaly sandstone (Cretaceous) is in some places composed in part of a conglomerate. Thickness, 150 feet.

7. Black slate, frequently a black shale, appears about a mile east of Drummond. This slate (shale) contains a bed of coarse conglomerate which at other places seems to be reduced to a sandstone. Thickness varies from 300 to 500 feet.

8. White quartzite, varying to sandstone, 30 to 400 feet.

9. Dark, nearly black limestone, 30 to 100 feet. This contains numerous gastropod fossils and serves as a datum for working out stratigraphy seen at Drummond.

10. Fine, white, cherty quartzite, 50 feet. This varies to a gray sandstone.

11. Coarse, red shale, 50 to 100 feet.

12. Gray sandstone, 800 feet. This carries sometimes heavy beds of green and black shales.

13. Black limestone, weathering buff, 75 to 150 feet. Dense, with conchoidal fracture.

14. Red sandstone, 50 feet.

15. Red sandstone and red shales, 150 feet.

16. Red sandstone, 20 feet, with some conglomerate, perhaps embraced in red shale.

17. Red shales and gray sandstones that weather red, 200 feet.

18. Gray sandstones, with Gryphæa, containing some conglomerate, 35 feet.

19. Shaly red sandstones and shales, 200 feet. In this sandstone is sometimes a conglomerate with quartzite and black pebbles.

20. Quartzite, reddish, 600 to 700 feet. Usually makes a prominent ridge; often contains pockets of hematite glistening with quartz facets.

21. Shales with a little sandstone, 200 to 300 feet. Usually red, but with some green and gray. Carries kidney iron ore.

22. Limestone, 200 to 300 feet, with gastropods (and *Sarcinula?*).

23. The main limestone mass, 2,700 feet; holds spirifer and crinoids; is the chief feature in the first hill-ranges of the region northward from Bearmouth and Garrison.

24. Black limestone (Trenton?), 100 feet.

25. Shale, reddish and often very silicious, 50 feet.

26. Quartzite (Potsdam?), 500 feet. Reddish to pinkish, and to white, sometimes spotted with buff white, passing to a fine conglomerate.

27. Quartzite (Potsdam?), 1,000 feet. Green, schistose, impure.

28. Argillite (Kintla, main mass), 3,000 feet. Red, green, and gray; fine-grained, like flint, thin-bedded, and with occasional intraformational conglomerates.

29. Red quartzite (Kintla), 1,500 feet. Coarser, varying to a fine conglomerate; composes "Mineral hill," north from Missoula.

30. Shaly argillite (Kintla), 700 feet. Red and gray, weathering to small fragments.

31. Red quartzite (Sheppard), 200 feet. Micaceous, fine grained, dark red.

32. Limestone (Siyeh), 3,000 feet. Light gray to dark gray, often brownish from iron ore, frequently shaly from much clay. Generally dolomitic, finely stratified, mural in aspect as a result of faulting.

33. Argillite (Grinnell), 1,500 feet. Base not seen. Purple, gray, red, and black; fine grained, slaty.

At present it is possible to give only the foregoing general section of the strata, with provisional designations of their geological ages, the fossils collected not yet having been studied.

Of the foregoing, numbers 7 to 21, inclusive, represent the Jura-Trias, as provisionally classified, and in this interval is a coal bed of economic promise, though the points at which this coal is best known are in the Flint Creek valley, a tributary of the Hellgate from the south.

In this series no plane of non-conformity was discovered. There seems to have been an unbroken sedimentation from the Algonkian to the base of the Cretaceous. The great limestone mass extends apparently from the Black River limestone to the commencement of the Mesozoic.

Cutting the Paleozoic is an intrusive granite, seen at Clinton and at Garnet. A system of porphyry dikes preceded it and another followed it, the latter penetrating the granite. It is along the margins of the earlier porphyry dikes, and more or less permeating the dikes themselves, that occur the gold ores and the free gold which has been taken from the placer mines of the region.

During the Cretaceous and at its close great igneous activity prevailed. Cretaceous volcanoes spread volcanic ash over extended areas. Much lava is found of later date than the Cretaceous, some of it being Tertiary. Crater pits are not uncommon, and dikes and sheets of white quartz porphyry are conspicuous at Bearmouth.

In general, there is a series of hill ranges or mountains, rising sometimes from 5,000 to 7,500 feet above the sea, which have a prevailing direction northwest-southeast throughout the area examined. These are produced evidently by a series of faults running in that direction, accompanied by lateral pressure, causing one side of the fault plane to drop while the other was lifted. Frequently the bold scarps face toward the northeast, and this is particularly the case in the Algonkian part of the area. Still this is not always the structure apparent. Some of the ranges are formed by sharp anticlinal folding. This great disturbance dates from later than some of the lavas, as these lavas are found to be faulted, and now form the crests of some of the fault scarps. It is evident, however, from the position of Tertiary strata in the Hellgate valley unconformable on the Algonkian, that the country had a bold relief at the opening of the Tertiary. The Hellgate river, through most of its course from Garrison to Bonner, runs in the valley produced by a succession of faulting, descending in the strata from east to west by cutting across such crests as it found thrown athwart its course.

DEVELOPMENT AND RELATIONSHIPS OF THE RUGOSA

BY J. E. DUERDEN *

STRUCTURAL RELATIONS OF THE GRANITES OF NORTH CAROLINA

BY THOMAS L. WATSON

This paper will be published in the reports of the North Carolina Geological Survey.

The President declared the scientific program closed.

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* Introduced by G. B. Shattuck.

Dr Robert Bell offered the following resolution of thanks, which was unanimously adopted:

Resolved, That the hearty thanks of the Society be extended to Professor J. A. Holmes for his kind and tactful assistance in planning the arrangements for the meeting and the social reunion; to the local committee of the American Association for the generous provision of the daily lunch, lantern, and other conveniences for the meeting; to the trustees of the Central High School for the use of rooms, and to the managers of the Exposition for the opportunity of seeing the grounds and buildings.

The meeting was declared adjourned.

Register of the Saint Louis Meeting, 1903–1904

The following Fellows were in attendance at the meeting:

F. D. Adams.
E. H. Barbour.
Robert Bell.
John C. Branner.
E. R. Buckley.
Samuel Calvin.
W. B. Clark.
A. P. Coleman.
A. J. Crook.
G. E. Culver.
E. R. Cumings.
W. M. Davis.
C. R. Dryer.
S. F. Emmons.
H. L. Fairchild.
O. C. Farrington.
G. K. Gilbert.
L. C. Glenn.
U. S. Grant.
F. P. Gulliver.
C. W. Hall.
Erasmus Haworth.
C. W. Hayes.
C. H. Hitchcock.
W. H. Hobbs.
J. A. Holmes.
E. O. Hovey.
C. R. Keyes.
G. E. Ladd.
T. H. Macbride.
W J McGee.
C. F. Marbut.
J. C. Merriam.
A. M. Miller.
W. G. Miller.
F. L. Ransome.
R. D. Salisbury.
G. B. Shattuck.
E. M. Shepard.
E. A. Smith.
R. S. Tarr.
J. E. Todd.
C. R. Van Hise.
David White.
I. C. White.
S. W. Williston.
A. N. Winchell.
R. S. Woodward.
G. F. Wright.

Fellows-elect

Samuel Weidman.
F. E. Wright.

Total attendance, 51.

SESSION OF THE CORDILLERAN SECTION, FRIDAY, JANUARY 1, 1904

The fifth annual meeting of the Cordilleran Section was called to order at 10 a m, January 1st, 1904, in South Hall, Berkeley.

In the absence of the Chairman of the Section, Professor E. W. Hilgard was elected Chairman pro tempore.

The minutes of the last meeting were read and approved.

An election of officers for the ensuing year was held, resulting in the election of E. W. Hilgard, Chairman of the Section, A. C. Lawson, Secretary, and Geo. D. Louderback, Councillor. These three officers are to serve as an Executive Committee for the year.

The following papers were then read and discussed:

A DETAIL OF THE GEOLOGY OF THE JOPLIN DISTRICT, MISSOURI

BY W. S. TANGIER SMITH

The substance of this paper is contained in a forthcoming report on the lead and zinc deposits of the Joplin district to be published by the U. S. Geological Survey.

NOTE ON THE FAUNA OF THE LOWER MIOCENE IN CALIFORNIA

BY JOHN C. MERRIAM

The paper has been published as a Bulletin of the Department of Geology of the University of California, vol. iii, no. 16.

STRATIGRAPHY OF THE SOUTHERN COAST RANGES OF CALIFORNIA

BY F. M. ANDERSON

[*Abstract*]

Contents

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Late sedimentary beds	582
Origin of bitumen	582

INTRODUCTORY

Rocks of various periods, ranging from Paleozoic to Recent, occur in the southern coast ranges of California, the latter being far more in evidence and having greater importance for their economic productions.

MIOCENE SERIES

Among the Tertiary rocks those of the Miocene period chiefly deserve attention, and are usually more easily recognized from their lithologic character. Of the undoubted Miocene sediments two divisions have been more or less perfectly described by former writers, though our present knowledge of them is far from complete. They have been called the Monterey shales and the Pescadero sandstones. The Pescadero sandstones, supposed to be the lowest member of the Miocene series, was first described from its occurrence along the coast north of Santa Cruz.

Locally its aggregate thickness has been estimated at over 11,000 feet. In the Carrisa valley of San Luis Obispo county a similar series 14,000 feet in thickness occurs, dipping uniformly to the northeast at an angle of from 40 to 50 degrees. The series consists of alternate beds of shales and sandstones, of which the latter forms the predominating element. There are three distinct divisions composed entirely of the shales. The sandstones are usually more fossiliferous and constitute four-fifths of the series.

The Monterey shales constitute the most characteristic portion of the Miocene rocks. At least four elements enter generally into their composition, and locally are more or less segregated. These elements are organic silica, volcanic ash, sand and lime carbonate. There are three stratigraphic divisions that may be distinguished in most districts, though not of equal importance. A representative section of the Miocene shales exposed in western Santa Barbara county comprises the following:

	Feet.
Diatom shale	800
Hard silicious shale	2,400
Sandy beds with lime	200

The sandy beds at the base of the series contain fossil invertebrates, among which the characteristic forms are *Amuseum, Pecten crassicardo Pecten discus* Conrad, *Scutella brewerianus?* Gabb., *Leda* sp. *cardium*, *Terebratella* (*Laqueus*), etcetera. In some districts, as in the vicinity of Temblor, Kern county, there is more shale and sandstone below the beds characterized by these fossils.

Late sedimentary Beds

Two or more series of late sedimentary rocks are often found overlying the Miocene beds, the more widely distributed being the San Pablo beds. The San Pablo rocks are mostly soft sandstones, often very fossiliferous. In Fresno county the thickness is locally more than 6,000 feet. The Merced series, or almost its equivalent, occurs in western Santa Barbara county and in Ventura and Los Angeles counties. Fresh-water deposits are widely spread through all the larger basins, as in the San Joaquin and Salinas valleys, and apparently in the desert region of Mojave. Glacier deposits in the form of drift occur abundantly about the higher rangers and on the borders of the Kern valley, having in some places a depth of 200 to 300 feet.

Origin of Bitumen

In all of the important petroleum districts of this region organic remains of microscopic size are found in sufficient numbers to support the view of an organic origin for the bitumens. Diatoms, foraminifera, and radiolaria occur in enormous numbers in some of the strata, and very often in strata saturated with petroleum. Sufficient notice has not yet been taken of this fact.

Remarks were made by A. C. Lawson.

The Section then took a recess.

At 2 o'clock p m the Section was called to order, Professor Hilgard in the chair.

The following papers were then read and discussed:

FAULT-PLANES IN THE DAKOTA FIRE-CLAY BEDS AT GOLDEN, COLORADO

BY HORACE B. PATTON

[*Abstract*]

Since the field work was completed preparatory to the publication of United States Geological Survey Monograph, number 27, entitled "Geology of the Denver Basin in Colorado," many interesting openings have been made in the Dakota formations in connection with the mining of the fire-clay that characterizes this formation in the vicinity of Golden. Extremely interesting faulting has thus been brought to light. Three distinct kinds of faults are to be seen in the present clay mines. The object of this paper, however, is to call attention to one particular fault, as shown by actual mining operations. The fire-clay bed stands nearly vertical and crops out near the crest of a pronounced hogback. After working out the clay from the surface a tunnel was run from the base of the hogback for the purpose of cutting the fire-clay bed at a lower level; but the crosscut tunnel failed to cut the fire-clay, although it was run far beyond the place where the clay should have been struck. At length, after fruitless searching for the missing fire-clay, the manager sank a winze from the upper workings following the nearly vertical fire clay bed. When about 10 feet above the level of the crosscut tunnel the bed was found to be faulted by a reverse fault in such a way as to produce a barren gap through which the tunnel chanced to be driven. Such practical applications of the laws of geology to mining operations are of special interest to those engaged in teaching geology. The paper will be published later with detailed drawings which could not be prepared at the present time owing to a cave-in at the mine.

GEOGRAPHIC DEVELOPMENT OF THE BOLIVIAN PLATEAU

BY W. G. TIGHT

A CROSS-SECTION OF THE COAST RANGES OF CALIFORNIA IN THE VICINITY OF MOUNT SAINT HELENA

BY V. C. ORMONT*

The paper will probably appear as a Bulletin of the Department of Geology, University of California.

The section then adjourned.

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*Presented by A. C. Lawson.

SESSION OF THE CORDILLERAN SECTION, SATURDAY, JANUARY 2

The section was called to order at 10 a m, January 2, 1904, Professor Hilgard in the chair.

The following papers were read and discussed :

GLACIATION ON THE HIGH PLATEAU OF BOLIVIA, SOUTH AMERICA

BY W. G. TIGHT

[*Abstract*]

The region under consideration includes the great elevated basin at the northern end of which is located lake Titicaca and the Cordilleras Real, which form the eastern wall of the basin, which are commonly known as the eastern Andes of Bolivia. The western rim of the basin is marked by the high line of volcanic mountains which run in a general northwest and southeast direction, roughly parallel to the west coast of South America. The Cordilleras Real were studied somewhat in detail for a distance of about 150 miles in length in the region lying directly east of lake Titicaca and between the high peaks of Illamani near La Paz and mount Sorata. These peaks reach an elevation of over 23,000 feet above the sea. South of mount Illamani the Cordilleras have been cut through by the La Paz river, which rises on the western slopes of the mountains. North of mount Sorata the Sorata river has also cut through the axis of the range, and extended its headwaters many miles to the southward along the western side of the mountains. The topographic features are very different on the two slopes of this great mountain system, due to the fact that on the western side the baselevel of erosion is the level of the Titicaca basin which is approximately 12,500 feet above the sea, while on the eastern side the baselevel of erosion extends down to the low basin of the Amazon.

As a result the eastern slopes are very rough and rugged and the mountain gorges of great magnitude as compared to those of the western side of the axis of the system.

The rainfall is also very great as compared to that of the western side, so that all the streams on the east carry a much greater volume of water. The eastern streams are encroaching very rapidly onto the drainage areas of the western streams. Among these encroaching streams the La Paz river has been most active. After working its way through the axis of the system its headwaters have discovered a vast system of stratified sands, gravels, and clays, which fill the great interior Titicaca basin. Into these easily eroded deposits the streams are working rapidly toward lake Titicaca. Near the city of La Paz the walls of the valley stand in almost vertical cliffs, exposing the strata for a depth of almost 2,000 feet. These strata are composed of stratified beds of gravel, sands, and clays.

The clay layers are typical boulder clays of evident glacial origin. Near the top of the series is a bed of boulder clay, about 250 feet thick, in which almost every stone, from those a fraction of an inch in diameter up to boulders weighing thousands of pounds, are most perfectly striated and polished. Striated pebbles and boulders were found very generally distributed throughout the entire series, being wanting only in the perfectly sorted and bedded gravels of the lower beds.

At about midway in this series of glacial deposits as exposed in the valley near La Paz is a bed of volcanic tuff some 20 to 60 feet in thickness. As there are no volcanic rocks known in the Cordilleras Real in this region, it is evident this tuff must have come from some of the volcanic cones on the western side of the plateau basin, some 60 miles distant. At a short distance below the tuff there is a wel marked soil zone, very rich in organic matter. Out of these evident glacial deposits is cut the great valley of the upper La Paz river. A few miles above the city of La Paz, in the La Paz River valley, there is developed a massive series of moraines, both lateral and terminal, filling the valley to an elevation of between 300 to 400 feet. These moraines now stand at an elevation of about 12,500 feet above the sea and are of the characteristic valley type. The floor of this old valley glacier is well marked, and where it reveals the rocks near its upper portion the rocks are perfectly striated and polished. Following up this old glacial floor into the higher regions the old cirques are very clearly shown, but do not carry perpetual snows at the present time. The present glaciers are confined to the minor high mountain gorges and valleys which feed into the old cirques. The lower limit of the present glaciers is now about 17,000 feet above the sea. The upper portion of the valley of the La Paz is cut partly in the glacial series of the Titicaca basin and partly in the shales and slates forming the mountain axis, but the valley is quite uniform in its characteristics and bears unmistakable evidence of being entirely a valley of river erosion, and the ancient glacier which occupied it produced very little effect on the general form of the valley. In the valley of the Sorata there was a great valley glacier, similar to the one in the La Paz valley, which extended down to at least 7,000 feet above sealevel. Evidence of these valley glaciers appears on most of the mountains of the plateau, on both the east and west sides of the Titicaca basin. Many of these mountains, whose summits do not now rise into the region of perpetual snows, have a system of very marked moraines on their flanks extending down to a level of the floor of the Titicaca basin.

The glacial succession in this region can easily be divided with three major divisions with well marked interglacial intervals. The first period was evidently of greatest duration and extent. The interglacial interval between the second and third periods is marked by the erosion of the great valley of the La Paz and Sorata rivers. Since the last period the glaciers have receded from an elevation of abont 8,000 feet to 17,000 feet above the sealevel.

Extending southward from lake Titicaca for a distance of about 600 miles is an extensive plain bordered on the east by the Cordilleras Real and on the west by a long chain of volcanic mountains, several of which show still some activity. The plain is very level, with many mountain cones rising abruptly from its surface, showing that the plain has been built up around the mountains, burying the ancient topography. The material of the plain is the finest silt, such as would be carried in suspension in water. Scattered over the surface are numerous shallow salt lakes and the large fresh water lake Poopo, which receives the discharge from lake Titicaca, through the Desaquadero river. Lake Poopo has an underground outlet to the Pacific.

Over large areas in the southern portion of this plain there is a layer of salt varying from slight incrustation to 2 feet in thickness. In certain more isolated embayments of the plain are extensive borax deposits.

On all the mountain slopes bordering the plain and also encircling the mountains which rise out of the plain there is a series of three well marked beachlines, the highest being about 350 feet above the plain. These three beaches are correlated with the three periods of glaciation, when the extensive glaciation on the bordering mountains supplied the water to fill the basin, the first and maximum glaciation corresponding to the highest beach, while the present minimum glaciation marks the evaporation of the waters of the basin and the deposition of the salts, while some seismic action has opened the underground outlet for the present fresh-water drainage.

The evidence of very extensive glaciation on the Bolivian plateau in very recent geologic time marked by three very distinct periods is well established, but the exact time relation to the Pleistocene glaciations of North America remains still to be determined.

THE COLD-WATER CURRENTS OF THE PACIFIC COAST OF THE UNITED STATES

BY R. S. HOLWAY*

THE GEOMORPHOGENY OF THE UPPER KERN BASIN

BY A. C. LAWSON

The paper has been published as a Bulletin of the Department of Geology, University of California, volume iii, number 15.

A committee, consisting of W. S. T. Smith, A. S. Eakle, and A. C. Lawson, was appointed by the Chair to prepare a suitable resolution on the death of Professor W. C. Knight.

The section then adjourned.

REGISTER OF THE BERKELEY MEETING OF THE CORDILLERAN SECTION, JANUARY 1 AND 2, 1904

The following Fellows were in attendance at the meeting:

F. M. ANDERSON.
A. S. EAKLE.
E. W. HILGARD.
A. C. LAWSON.
G. D. LOUDERBACK.
H. B. PATTON.
W. S. TANGIER SMITH.
W. G. TIGHT.
H. W. TURNER.

The visitors were

R. S. HOLWAY.
W. J. SHARWOOD.
W. J. SINCLAIR.
D. T. SMITH.

ANDREW C. LAWSON,
Secretary.

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* Introduced by A. C. Lawson.

ACCESSIONS TO LIBRARY FROM JUNE, 1903, TO JULY, 1904

BY H. P. CUSHING, *Librarian*

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(*A*) FROM SOCIETIES AND INSTITUTIONS RECEIVING THE BULLETIN AS DONATION ("EXCHANGES")

(*a*) *AMERICA*

NEW YORK STATE MUSEUM, ALBANY

2477–2479. Annual Report, no. 54, parts 2–4.
2480. " " no. 55.
2483–2490. Bulletins 59–72.

BOSTON SOCIETY OF NATURAL HISTORY, BOSTON

2328. Proceedings, vol. 31, nos. 2–7.
2521. Memoirs, vol. 5, no. 11.

MUSEO NACIONAL DE BUENOS AIRES, BUENOS AIRES

2533. Anales, serie 3, tomo ii.

CHICAGO ACADEMY OF SCIENCES, CHICAGO

FIELD COLUMBIAN MUSEUM, CHICAGO

1916. Zoological series, vol. iii, nos. 10–16.
2402. Geological series, vol. ii, nos. 1–4.
2181. Report series, vol. ii, no. 3.

CINCINNATI SOCIETY OF NATURAL HISTORY, CINCINNATI

2149. Journal, vol. xx, no. 4.

COLORADO SCIENTIFIC SOCIETY, DENVER

2398. Partial Proceedings, vol. vii.

NOVA SCOTIAN INSTITUTE OF SCIENCE, HALIFAX

MUSEO DE LA PLATA, LA PLATA

INSTITUTO GEOLOGICO DE MEXICO, MEXICO

2504. Parergones, tomo i, no. 1.

NATURAL HISTORY SOCIETY OF MONTREAL, MONTREAL

2401. Canadian Record of Science, vol. ix, nos. 1–2.

AMERICAN GEOGRAPHICAL SOCIETY, NEW YORK

2326. Bulletin, vol. xxxv, nos. 2–5, 1903.
2542. “ “ xxxvi, nos. 1–5, 1904.

AMERICAN MUSEUM OF NATURAL HISTORY, NEW YORK

2465. Memoirs, vol. i, part 8.
2491. Bulletin, vol. xix, 1903.
2266. “ “ xviii, part 2.
2540. “ “ xx, supplement.
1693. Annual Report of the President, etcetera, 1903.

NEW YORK ACADEMY OF SCIENCES, NEW YORK

2083. Annals, vol. xiv, part 4.
2443. “ “ xv, parts 1–2.

AMERICAN INSTITUTE OF MINING ENGINEERS, NEW YORK

2466–2476. Transactions, vols. xxii–xxxii.
2503. “ vol. xxxiii, 1902.

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2124. Catalogue of Canadian Birds, part 2, 1903.
2403. Annual Report, new series, vol. xii, 1899.
2462. Geologic sheets, nos. 42–48, 56–58, Nova Scotia.
2512. Altitudes in Canada.

ROYAL SOCIETY OF CANADA, OTTAWA

2425. Proceedings and Transactions, second series, vol. viii.

ACADEMY OF NATURAL SCIENCES, PHILADELPHIA

Proceedings, vol. lv, parts 1–3, 1903.

AMERICAN PHILOSOPHICAL SOCIETY, PHILADELPHIA

2354. Proceedings, vol. xlii, 1903.

MUSEO NACIONAL DE RIO DE JANEIRO, RIO DE JANEIRO

CALIFORNIA ACADEMY OF SCIENCES, SAN FRANCISCO

2409. Memoirs, vol. iii, 4to.
2509. Constitution.

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ACADEMY OF SCIENCE, ST LOUIS

2424. Transactions, vol. xiii, 1903.

COMISSAO GEOGRAPHICA E GEOLOGICO, SAO PAULO

NATIONAL GEOGRAPHIC SOCIETY, WASHINGTON

2292. National Geographic Magazine, vol. xiv, nos. 7–12.
2461. “ “ “ “ xv, nos. 1–6.

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SMITHSONIAN INSTITUTION, WASHINGTON

2448. Annual Report, 1902.
2497. International Exchange List.

UNITED STATES GEOLOGICAL SURVEY, WASHINGTON

2393–2395. Monographs xlii–xliv.
2306. Bulletin 205.
2396–2397. Bulletins 206–211.
2415. Twenty-third Annual Report.
2416–2419. Professional Papers 1–10 and 14.
2420–2423. Water Supply Papers 65–82.
2457. " " " 83–87.
2458–2459. Monograph xlv and atlas.
2515. Twenty-fourth Annual Report.
2516. Monograph xlvi.
2517–2518. Bulletins 215–225.
2535. " 226–227.
2534. Mineral Resources, 1902.
2536–2539. Professional Papers 11–13, 15–20.

UNITED STATES NATIONAL MUSEUM, WASHINGTON

(b) *EUROPE*

DEUTSCHE GEOLOGISCHE GESELLSCHAFT, BERLIN

2244. Zeitschrift, band liv, heft 3–4, 1902.
2438. " " lv, heft 1–3, 1903.

KÖNIGLICH PREUSSISCHEN GEOLOGISCHEN LANDESANSTALT UND BERGAKADEMIE, BERLIN

GEOGRAPHISCHEN GESELLSCHAFT, BERNE

SCHWEIZ. GEOLOGISCHEN KOMMISSION, BERNE

1746. Geotechnische serie lieferung 2.

R. ACCADEMIA DELLE SCIENZE DELL' INSTITUTO DI BOLOGNA, BOLOGNA

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2446. Two reports on Phosphate Discoveries.
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2527. Review of Mining Operations in South Australia during 1903.

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2315. Reports 181-189, including geological map of Queensland.

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2344. Records of the Geological Survey, vol. i, part 2.
2405. Bulletins, nos. i–ii.
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2441. Geologic Maps of Chiltern Gold Field and County of Rodney.
2317. Annual Report of the Secretary of Mines for 1902.
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2138. Annual Report for 1902.
2463. Bulletins nos. 8–10.
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2529. Dictionary of Altitudes in Canada.

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2295. Quantitative Classification of Igneous Rocks.

EDWARD V. D'INVILLIERS

2565. Estimated Costs of Mining and Coking * * * in the Connellsville and Walston-Reynoldsville Districts, Pennsylvania.

H. L. FAIRCHILD

2566. Pleistocene Geology of Western New York, Progress Report, 1900.
2567. Latest and Lowest Pre-Iroquois Channels between Syracuse and Rome.

PERSIFOR FRAZER

2568. Alphabetical Cross-Reference Catalogue of the Publications of the late Edward Drinker Cope.
2569. Catalogue Chronologique des Publicationes de Edward Drinker Cope.

EZEQUIEL ORDONEZ

2570. Les Cendres d'un Volcan près de Santa Maria (Guatemala).
2571. Le Xinantecal ou Volcan Nevado de Toluca.

JOSEPH HYDE PRATT

2573. The Mining Industry of North Carolina during 1901.
2574. Ten Separates from the Mineral Resources of the United States, 1902.

J. W. SPENCER

2575. On the Geological and Physical Development of Antigua, Guadeloupe, Dominica, Barbadoes, Anguilla, etcetera.

HENRY S. WASHINGTON

2576. Chemical Analyses of Igneous Rocks.

(*E*) FROM MISCELLANEOUS SOURCES

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2577. Rapport sur les Observations glaciares en Haute-Marienne, dans les Grandes-Rousses et L'Oisans, dans l'Été de 1902.

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2578. Observations sur l'Enneigement et sur les Chutes Avalanches.

G. HENRICKSEN, CHRISTIANA

2579. On the Iron Ore Deposits in Sydvaranger etcetera.

J. KRZYZANOWSKI AND ST WYSOCKI, PARIS

2580. Noveau Système pour Combattre les Incendies dans les Mines.

MAX. LOHEST, ALFRED HABETS ET HENRI FORIR, LIEGE

2581. La Géologie et la Reconnaisance du Terrain Houiller du Nord de la Belgique.

MICHEL MOURLON, LIEGE

2582. Referendum Bibliographique, etcetera.
2583. Résultat du Referendum Bibliographique.

BORIS POPOFF, ST PETERSBURG

2584. Ueber Rapakiwi aus Süd-Russland.

FERDINAND VON RICHTHOFEN, BERLIN

2223. Geomorphologie Studien aus Ostasien:
    III. Die morphologische Stellung von Formosa und den Riukiu-Inseln.
    IV. Ueber Gebirgskettungen in Ostasien, mit Ausschluss von Japan.
    V. Gebirgskettungen im japanischen Bogen.

CONSTITUTION AND BY-LAWS

REFERENCES TO ADOPTION AND CHANGES

The provisional Constitution under which the Society was organized was approved August 15, 1888, and adopted December 27, 1888 (see Bulletin, volume 1, pages 7–8). These rules were elaborated and the revised Constitution and By-Laws were adopted December 27, 1889 (volume 1, pages 536, 571–578).

Several minor changes have been made in these rules, which are on record in the Bulletin as follows: Changes in the Constitution: December, 1894, volume 6, page 432; December, 1897, volume 9, page 400. Changes in the By-Laws: December, 1891, volume 3, page 470; December, 1893, volume 5, pages 553–554; December, 1894, volume 6, page 432; December, 1903, volume 14, page 535.

CONSTITUTION

Article I

NAME

This Society shall be known as The Geological Society of America.

Article II

OBJECT

The object of this Society shall be the promotion of the Science of Geology in North America.

Article III

MEMBERSHIP

The Society shall be composed of Fellows, Correspondents, and Patrons.

1. Fellows shall be persons who are engaged in geological work or in teaching geology.

Fellows admitted without election under the provisional Constitution shall be designated as Original Fellows on all lists or catalogues of the Society.

2. Correspondents shall be persons distinguished for their attainments in Geological Science and not resident in North America.

3. Patrons shall be persons who have bestowed important favors upon the Society.

4. Fellows alone shall be entitled to vote or hold office in the Society.

Article IV

OFFICERS

1. The Officers of the Society shall consist of a President, First and Second Vice-Presidents, a Secretary, a Treasurer, an Editor, and six Councilors.

These officers shall constitute an Executive Committee, which shall be called the Council.

2. The President shall discharge the usual duties of a presiding officer at all meetings of the Society and of the Council. He shall take cognizance of the acts of the Society and of its officers, and cause the provisions of the Constitution and By-Laws to be faithfully carried into effect.

3. The First Vice-President shall assume the duties of President in case of the absence or disability of the latter. The Second Vice-President shall assume the duties of President in case of the absence or disability of both the President and First Vice-President.

4. The Secretary shall keep the records of the proceedings of the Society, and a complete list of the Fellows, with the dates of their election and disconnection with the Society. He shall also be the secretary of the Council.

The Secretary shall coöperate with the President in attention to the ordinary affairs of the Society. He shall attend to the preparation, printing and mailing of circulars, blanks and notifications of elections and meetings. He shall superintend other printing ordered by the Society or by the President, and shall have charge of its distribution, under the direction of the Council.

The Secretary, unless other provision be made, shall also act as Editor of the publications of the Society, and as Librarian and Custodian of the property.

5. The Treasurer shall have the custody of all funds of the Society. He shall keep account of receipts and disbursements in detail, and this shall be audited as hereinafter provided.

6. The Editor shall supervise all matters connected with the publication of the transactions of the Society under the direction of the Council.

7. The Council is clothed with executive authority and with the legislative powers of the Society in the intervals between its meetings; but no extraordinary act of the Council shall remain in force beyond the next following stated meeting without ratification by the Society. The Council shall have control of the publications of the Society, under provisions of the By-Laws and of resolutions from time to time adopted. They shall receive nominations for Fellows, and, on approval by them, shall submit such nominations to the Society for action. They shall have power to fill vacancies *ad interim* in any of the offices of the Society.

8. *Terms of Office.*—The President and Vice-Presidents shall be elected annually, and shall not be eligible to re-election more than once until after an interval of three years after retiring from office.

The Secretary-Treasurer and Editor shall be eligible to re-election without limitation.

The term of office of the Councilors shall be three years; and these officers shall be so grouped that two shall be elected and two retire each year. Councilors retired shall not be re-eligible till after the expiration of a year.

ARTICLE V

VOTING AND ELECTIONS

1. All elections shall be by ballot. To elect a Fellow, Correspondent or Patron, or impose any special tax, shall require the assent of nine-tenths of all Fellows voting.

2. Voting by letter may be allowed.

3. *Election of Fellows.*—Nominations for fellowship may be made by two Fellows according to a form to be provided by the Council. One of these Fellows must be

personally acquainted with the nominee and his qualifications for membership. The Council will submit the nominations received by them, if approved, to a vote of the Society in the manner provided in the By-Laws. The result may be announced at any stated meeting; after which notice shall be sent out to Fellows elect.

4. *Election of Officers.*—Nominations for office shall be made by the Council. The nominations shall be submitted to a vote of the Society in the same manner as nominations for fellowship. The results shall be announced at the Annual Meeting; and the officers thus elected shall enter upon duty at the adjournment of the meeting.

ARTICLE VI

MEETINGS

1. The Society shall hold at least two stated meetings a year—a Summer Meeting at the same locality and during the same week as the annual meeting of the American Association for the Advancement of Science—and a Winter Meeting. The date and place of the Winter Meeting shall be fixed by the Council, and announced by circular each year within a month after the adjournment of the Summer Meeting. The program of each Meeting shall be determined by the Council, and announced beforehand, in its general features. The details of the daily sessions shall also be arranged by the Council.

2. The Winter Meeting shall be regarded as the Annual Meeting. At this, elections of Officers shall be declared, and the officers elect shall enter upon duty at the adjournment of the Meeting.

3. Special Meetings may be called by the Council, and must be called upon the written request of twenty Fellows.

4. Stated Meetings of the Council shall be held coincidently with the Stated Meetings of the Society. Special meetings may be called by the President at such times as he may deem necessary.

5. *Quorum.*—At meetings of the Society a majority of those registered in attendance shall constitute a quorum. Five shall constitute a quorum of the Council.

ARTICLE VII

PUBLICATION

The serial publications of the Society shall be under the immediate control of the Council.

ARTICLE VIII

AMENDMENTS

1. This Constitution may be amended at any annual meeting by a three-fourths vote of all the Fellows, provided that the proposed amendment shall have been submitted in print to all Fellows at least three months previous to the meeting.

2. By-laws may be made or amended by a majority vote of the Fellows present and voting at any annual meeting, provided that printed notice of the proposed amendment or by-law shall have been given to all Fellows at least three months before the meeting.

BY-LAWS

CHAPTER I

OF MEMBERSHIP

1. No person shall be accepted as a Fellow unless he pay his initiation fee, and the dues for the year, within three months after notification of his election. The initiation fee shall be ten (10) dollars and the annual dues ten (10) dollars, the latter payable on or before the annual meeting in advance; but a single prepayment of one hundred (100) dollars shall be accepted as commutation for life.

2. The sums paid in commutation of dues shall be covered into the Publication Fund.

3. An arrearage in payment of annual dues shall deprive a Fellow of the privilege of taking part in the management of the Society and of receiving the publications of the Society. An arrearage continuing over two (2) years shall be construed as notification of withdrawal.

4. Any person eligible under Article III of the Constitution may be elected Patron upon the payment of one thousand (1,000) dollars to the Publication Fund of the Society.

CHAPTER II

OF OFFICIALS

1. The President shall countersign, if he approves, all duly authorized accounts and orders drawn on the Treasurer for the disbursement of money.

2. The Secretary, until otherwise ordered by the Society, shall perform the duties of Editor, Librarian, and Custodian of the property of the Society.

3. The Society may elect an Assistant Secretary.

4. The Treasurer shall give bonds, with two good sureties approved by the Council, in the sum of five thousand dollars, for the faithful and honest performance of his duties and the safe-keeping of the funds of the Society. He may deposit the funds in bank at his discretion, but shall not invest them without authority of the Council. His accounts shall be balanced as on the thirtieth day of November of each year.

5. In the selection of Councilors the various sections of North America shall be represented as far as practicable.

6. The minutes of the proceedings of the Council shall be subject to call by the Society.

7. The Council may transact its business by correspondence during the intervals between its stated meetings; but affirmative action by a majority of the Council shall be necessary in order to make action by correspondence valid.

CHAPTER III

OF ELECTION OF MEMBERS

1. Nominations for fellowship may be proposed at any time on blanks to be supplied by the Secretary.

2. The *form* for the nomination of Fellows shall be as follows :

In accordance with his desire, we respectfully nominate for Fellow of the Geological Society of America:

Full name; degrees; address; occupation; branch of Geology now engaged in, work already done and publications made.

(Signed by at least two Fellows.)

The form when filled is to be transmitted to the Secretary.

3. The Secretary will bring all nominations before the Council, at either the Winter or Summer Meeting of the Society, and the Council will signify its approval or disapproval of each.

4. At least a month before one of the stated meetings of the Society the Secretary will mail a printed list of all approved nominees to each Fellow, accompanied by such information as may be necessary for intelligent voting; but an informal list of the candidates shall be sent to each Fellow at least two weeks prior to distribution of the ballots.

5. The Fellows receiving the list will signify their approval or disapproval of each nominee, and return the lists to the Secretary.

6. At the next stated meeting of the Council the Secretary will present the lists and the Council will canvass the returns.

7. The Council, by unanimous vote of the members in attendance, may still exercise the power of rejection of any nominee whom new information shows to be unsuitable for fellowship.

8. At the next stated meeting of the Society the Council shall declare the results.

9. Correspondents and Patrons shall be nominated by the Council, and shall be elected in the same manner as Fellows.

Chapter IV

OF ELECTION OF OFFICERS

1. The Council shall prepare a list of nominations for the several offices, which list will constitute the regular ticket. This ticket must be approved by a majority of the entire Council. The nominee for President shall not be a member of the Council.

2. The list shall be mailed to the Fellows, for their information, at least nine months before the Annual Meeting. Any five Fellows may forward to the Secretary other nominations for any or all offices. All such nominations reaching the Secretary at least 40 days before the Annual Meeting shall be printed, together with the names of the nominators, as special tickets. The regular and special tickets shall then be mailed to the Fellows at least 25 days before the Annual Meeting.

3. The Fellows will send their ballots to the Secretary in double envelopes, the outer envelope bearing the voter's name. At the winter meeting of the Council, the Secretary will bring the returns of ballots before the Council for canvass, and during the winter meeting of the Society the Council shall declare the result.

4. In case a majority of all the ballots shall not have been cast for any candidate for any office, the Society shall by ballot at such winter meeting proceed to make an election for such office from the two candidates having the highest number of votes.

Chapter V

OF FINANCIAL METHODS

1. No pecuniary obligation shall be contracted without express sanction of the Society or the Council. But it is to be understood that all ordinary, incidental, and running expenses have the permanent sanction of the Society, without special action.

2. The creditor of the Society must present to the Treasurer a fully-itemized bill, certified by the official ordering it, and approved by the President. The Treasurer

shall then pay the amount out of any funds not otherwise appropriated, and the receipted bill shall be held as his voucher.

3. At each annual meeting, the President shall call upon the Society to choose two Fellows, not members of the Council, to whom shall be referred the books of the Treasurer, duly posted and balanced to the close of November thirtieth, as specified in the By-Laws, Chapter II, Clause 4. The Auditors shall examine the accounts and vouchers of the Treasurer, and any member or members of the Council may be present during the examination. The report of the Auditors shall be rendered to the Society before the adjournment of the meeting, and the Society shall take appropriate action.

Chapter VI

OF PUBLICATIONS

1. The publications are in charge of the Council and under its control.

2. One copy of each publication shall be sent to each Fellow, Correspondent, and Patron, and each author shall receive thirty (30) copies of his memoir.

Chapter VII

OF THE PUBLICATION FUND

1. The Publication Fund shall consist of donations made in aid of publication, and of the sums paid in commutation of dues, according to the By-Laws, chapter I, clause 2.

2. Donors to this fund, not Fellows of the Society, in the sum of two hundred dollars, shall be entitled, without charge, to the publications subsequently appearing.

Chapter VIII

OF ORDER OF BUSINESS

1. The Order of Business at Winter Meetings shall be as follows:
    (1) Call to order by the presiding officer.
    (2) Introductory ceremonies.
    (3) Report of the Council (including report of the officers).
    (4) Appointment of the Auditing Committee.
    (5) Declaration of the vote for officers, and election by the meeting in case of failure to elect by the Society through transmitted ballots.
    (6) Declaration of the vote for Fellows.
    (7) Deferred business.
    (8) New business.
    (9) Announcements.
    (10) Necrology.
    (11) Reading of scientific papers.

2. At an adjourned session the order shall be resumed at the place reached on the previous adjournment, but new business will be in order before the reading of scientific papers.

3. At the Summer Meeting the items of business under numbers (3), (4), (5), (10) shall be omitted.

4. At any Special Meeting the order of business shall be numbers (1), (2), (3), (9), followed by the special business for which the meeting was called.

PUBLICATION RULES

(*Adopted by the Council April 21, 1891; Revised April 30, 1894, and May, 1904*)

GENERAL PROVISIONS

SECTION 1. The Council shall annually appoint from their own number a Publication Committee, consisting of the Secretary and two others, whose duties shall be to determine the disposition of matter offered for publication, except as provided in Section 17; to determine the expediency, in view of the financial condition of the Society, of publishing any matter accepted on its merits; to exercise general oversight of the matter and manner of publication; to determine the share of the cost of publication (including illustrations) to be borne by the author when it becomes necessary to divide cost between the Society and the author; to adjudicate any questions relating to publication that may be raised from time to time by the Editor or by the Fellows of the Society; and in general to act for the Council in all matters pertaining to publication. (Cons., Art. IV, 7; Art. VII; By-laws, chap. VI.)

2. The duties of the Editor are to receive material offered for publication; to examine and submit same with estimates of cost to the Publication Committee; to publish all material accepted by the Council or Publication Committee; to revise proofs in connection with authors; to prepare lists of contents and general indices; to audit bills for printing and illustrating; and to perform all other duties connected with publication not assigned to other officers. (Cons., Art. IV, 6; Rules, Sec. 16.)

3. The duties of the Secretary include the preparation of a record of the proceedings of each meeting of the Society in form for publication, and the custody, distribution, sale, exchange or other authorized disposition of the publications. (Constitution, Art. IV, 4; By-laws, chap. II, 2.)

4. Special committees may be appointed by the Council or the Publication Committee to examine and report on any matter offered for publication. (Rules, Sec. 16.)

THE BULLETIN

TITLE AND GENERAL CHARACTER

5. The Society shall publish a serial record of its work entitled "Bulletin of the Geological Society of America."

6. The Bulletin shall be published, for immediate distribution, in covered parts or brochures, consecutively paged for each volume. The brochures shall be designated by volume numbers and limiting pages, and each shall bear a special title setting forth the contents and authorship, the seal and imprint of the Society and the date of publication (Rules, Sec. 27). The Bulletin shall also be published in complete volumes, and each volume shall comprise the issue of a calendar year.

7. The brochures shall be memoir brochures and brochures of proceedings.

8. Each memoir brochure shall consist normally of a single memoir or article, either accompanied by discussion or not; it may consist exceptionally of two or more memoirs where the subject-matter is closely related.

9. The proceedings of the annual, summer, and special meetings of the Society, prepared by the Secretary (including short papers, abstracts, etc.), shall be published as separate brochures as soon as may be after these meetings.

10. The proceedings of the annual meeting shall form the closing portion of the volume for the year.

11. The brochure containing the proceedings of the annual meeting shall contain an index, paged consecutively with the body of the volume; and it shall be accompanied by a volume title-page and lists of contents and illustrations, together with lists of the publications of the Society and such other matter as the Publication Committee may deem necessary, all arranged under Roman pagination.

MATTER OF THE BULLETIN

12. The matter published in the Bulletin shall comprise (1) communications presented at meetings by title or otherwise; (2) communications or memoirs not presented before the Society; (3) abstracts of papers read before the Society, prepared or revised for publication by authors; (4) reports of discussions made before the Society, prepared or revised for publication by authors; (5) proceedings of the meetings of the Society prepared by the Secretary; (6) plates, maps, and other illustrations necessary for the proper understanding of communications; (7) lists of Officers and Fellows, Constitution, By-laws, resolutions of permanent character, rules relating to procedure, to publication, and to other matters. etc.; and (8) indices, title-pages, and lists of contents for each volume.

13. Communications making sixteen or more printed pages of text, including figures, shall be published as memoir brochures. Communications making less than sixteen printed pages may be included in the proceedings brochures or published as memoir brochures, at the option of the individual authors; but in the latter case the number of pages shall not be less than eight, unless authorized by the Publication Committee, and the additional expense for brochure covers and distribution may be assessed on the authors.

14. Abstracts, reports of discussion, or other matter purporting to emanate from any author shall not be published unless prepared or revised by the author.

15. Manuscript designed for publication in the Bulletin must be complete as to copy for text and illustration, unless by special arrangement between the author and the Council or Publication Committee; it must be perfectly legible (preferably typewritten) and preceded by a table of contents (Sec. 20). The cost of necessary revision of copy or reconstruction of illustrations shall be assessed on the author.

16. The Editor shall examine matter designated for publication, and shall prepare an itemized estimate of the cost of publication and convey the whole to the Publication Committee. The Publication Committee shall then scrutinize the communication with reference, first, to relevancy; second, to scientific value; third, to literary character, and, fourth, to cost of publication, including revision. For advice with reference to the relevancy, scientific value, and literary character of any communication the Publication Committee may refer it to a special committee of their own number or of the Society at large or may call to their aid from outside one or more experts. Questions of disagreement between the Editor and authors shall be referred to the Publication Committee, and appeal may be taken to the Council.

17. Communications from non-fellows shall be published only by specific authority from the Council.

18. Communications from Fellows not presented at regular meetings of the Society shall be published only upon unanimous vote of the Publication Committee, except by specific authority from the Council.

19. Matter offered for publication becomes thereby the property of the Society, and shall not be published elsewhere prior to publication in the Bulletin, except by consent of the Publication Committee.

DETAILS OF THE BULLETIN

20. The matter of each memoir shall be classified by subjects, and the classification suitably indicated by subtitles; and a list of contents shall be arranged; and such brochure may, at the option of the Publication Committee, contain an alphabetical index, provided the author prepare and pay for same.

21. Proofs of text and illustrations shall be submitted to authors whenever practicable; but printing shall not be delayed by reason of absence or incapacity of authors more than one week beyond the time required for transmission by mail. Complete proofs of the proceedings of meetings shall be sent to the Secretary, and proofs of papers and abstracts contained therein and exceeding one-half page in length shall be sent also to authors. (Sec. 14.)

22. The cost of proof corrections in excess of five per cent on the cost of printing may be charged to authors.

23. Unless the author of a memoir objects thereto the discussion upon his communication shall be printed as the closing part of the brochure, with a suitable reference in the list of contents. In case the author objects to this arrangement, the discussion shall be printed in the proceedings.

24. The author of each memoir printed in brochure form shall receive 30 copies without charge, and may order through the Editor any edition of exactly similar brochures at cost of paper, presswork and binding; and no author's separates of the memoirs published as brochures shall be issued except in this regular form.

25. Authors of papers, abstracts, etc., in the proceedings brochure may order, through the Editor, at the cost of paper, presswork, binding and necessary composition, any number of extra copies, provided they bear the original pagination and a printed reference to the serial and volume from which they are extracted.

26. The Editor shall keep a record of all publications issued wholly or in part under the auspices of the Society, whether the same be authors' editions of the memoir brochures, authors' extracts from proceedings, or any other matter printed from type originally composed for the Bulletin.

DIRECTIONS TO PRINTER

25. Each brochure of the Bulletin shall begin, under its proper title, on an odd-numbered page bearing at its head the title of the serial, the volume number, the limiting pages, the plates, and the date of publication, together with a list of contents; each brochure shall be accompanied by the illustrations pertaining to it, the plates numbered consecutively for the volume.

28. Each brochure shall be enclosed in a cover bearing at the head of its title-page the title of the serial, the volume number, the limiting pages, and the numbers of the contained plates; in its upper-central part a title indicating the contents and authorship; in its lower-central part the seal of the Society; and at the bottom the imprint of the Society. Volume covers shall correspond to brochure covers, with proper volume designation on side and back.

29. The bottom of each signature and each initial page will bear a signature mark giving an abbreviated title of the serial, the volume, and the year; and every page (except volume title-page) shall be numbered, the initial and sub-title pages in parentheses at bottom.

30. The page-head titles shall be: on even-numbered pages, name of author and catch title of paper; on odd-numbered pages, catch title to contents of page.

31. The date of publication of each brochure shall be the day upon which the last form is locked and put upon the press.

32. The type used in printing the Bulletin shall be as follows: For memoirs, body, long primer, 6-to-pica leads; extracts, brevier, 8-to-pica leads; foot-notes, nonpareil, set solid; titles, long primer caps, with small caps for author's name; subtitles, long primer caps, small caps, italic, etc., as far as practicable; for designation of cuts, nonpareil caps and italics, and for legends, nonpareil, Roman, set solid; for lists of contents of brochures, brevier, 6-to-pica leads, a new line to an entry, running indentation; for volumes, the same, except 4-to-pica leads and names of authors in small caps; for indices, nonpareil, set solid, double column, leaders, catch words in small caps, with spaces between initial letters. For serial titles, on initial pages, brevier block caps, with corresponding small caps for volume designation, etc.; on covers, the same, except for page heads long primer caps; for serial designation, long primer; for brochure designation, pica caps; special title and author's name, etc., long primer and brevier caps; no frame on cover. No change in type shall be made to adjust matter to pages.

33. Volumes, plates, and cuts in text shall be numbered in Arabic; Roman numeration shall be used only in signature marks, and in paging the lists of contents, etc., arranged for binding at the beginning of the volume.

34. Imprimatur of Editor, on volume title-page; imprimatur of Council and Publication Committee, on obverse of volume title-page; imprimatur of Secretary, on initial pages and covers of brochures of proceedings. Printer's card, in fine type on obverse of title-page.

35. The paper shall be for body of volume, 70 lbs. toned paper, folding to 16 x 25 centimeters; for plates, good quality plate paper, smooth-surfaced, white, cut to 6½ x 10 inches for single plates; for covers smooth-surfaced, fine quality 100 lbs. light-buff manilla paper.

36. The sheets of the brochures shall be stitched with thread; single page plates shall be stitched with the sheets of the brochure; folding plates may be either gummed or stitched (mounted on stubs if necessary); covers shall be gummed.

EDITION, DISTRIBUTION, AND PRICE

37. The regular edition shall be 500 copies for the Society, and 30 copies for authors. If two or more authors contribute to a memoir brochure, the edition shall be enlarged so as to give each author 30 copies. (By-laws, chap. VI, 2.)

38. Of the 500 copies printed for the Society, a number exceeding by ten the number required for immediate distribution shall be bound as brochures; the remainder shall be gathered into volumes.

39. Each brochure shall be forwarded promptly on publication to Fellows and to such other regular recipients as shall elect that mode of distribution. On completion of a volume it shall be forwarded to other regular recipients.

40. The undistributed residue of volumes and brochures shall be held for sale.

41. The Bulletin shall be sent free to Fellows of the Society not in arrears for dues more than one year, and also to exchanging institutions. (By-laws, chap. I, 3.)

42. The price of the Bulletin shall be as follows: Volumes to Fellows at an advance of about fifty per cent on the cost (including incidentals, distribution, etc.), the amount being a multiple of fifty cents. The fixed price to libraries and institutions is $5 per volume, and to individuals $10. The price of each brochure shall be a multiple of five cents, and shall be, to Fellows, an advance on cost of about 100 per cent, and to the public, an advance on cost of about 200 per cent. The prices of volumes and brochures may be found in the front of each volume.

OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1904

President

John C. Branner, Stanford University, Cal.

Vice-Presidents

H. S. Williams, New Haven, Conn.
Samuel Calvin, Iowa City, Iowa.

Secretary

H. L. Fairchild, Rochester, N. Y.

Treasurer

I. C. White, Morgantown, W. Va.

Editor

J. Stanley-Brown, Washington, D. C.

Librarian

H. P. Cushing, Cleveland, Ohio.

Councillors

(Term expires 1904)

C. W. Hayes, Washington, D. C.
J. P. Iddings, Chicago, Ill.

(Term expires 1905)

R. D. Salisbury, Chicago, Ill.
J. E. Wolff, Cambridge, Mass.

(Term expires 1906)

John M. Clarke, Albany, N. Y.
George P. Merrill, Washington, D. C.

FELLOWS IN DECEMBER, 1904

*Indicates Original Fellow (see article III of Constitution)

Cleveland Abbe, Jr., Ph. D., 1441 Florida Ave. N. W., Washington, D. C. August, 1899.

Frank Dawson Adams, Ph. D., Montreal, Canada; Professor of Geology in McGill University. December, 1889.

George I. Adams, Sc. D., Corps of Mining Engineers, Lima, Peru. December, 1902.

José Guadalupe Aguilera, Esquela N. de Ingeneiros, City of Mexico, Mexico; Director del Instituto Geologico de Mexico. August, 1896.

Truman H. Aldrich, M. E., 1739 P St. N. W., Washington, D. C. May, 1889.

Henry M. Ami, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

Frank M. Anderson, B. A., M. S., 2604 Ætna Street, Berkeley, Cal. In California State Mining Bureau. June, 1902.

Philip Argall, 728 Majestic Building, Denver, Colo.; Mining Engineer. August, 1896.

George Hall Ashley, M. E., Ph. D., Washington, D. C., U. S. Geological Survey. August, 1895.

Harry Foster Bain, M. S., U. S. Geological Survey, Washington, D. C. December, 1895.

Rufus Mather Bagg, Ph. D., Socorro, N. Mex.; Professor of Mineralogy and Petrography, State School of Mines. December, 1896.

S. Prentiss Baldwin, 736 Prospect St., Cleveland, Ohio. August, 1895.

Erwin Hinckley Barbour, Ph. D., Lincoln, Neb.; Professor of Geology, University of Nebraska, and Acting State Geologist. December, 1896.

Joseph Barrell, Ph. D., New Haven, Conn.; Assistant Professor of Geology, Yale University. December, 1902.

George H. Barton, B. S., Boston, Mass.; Instructor in Geology in Massachusetts Institute of Technology. August, 1890.

Florence Bascom, Ph. D., Bryn Mawr, Pa.; Instructor in Geology, Petrography, and Mineralogy in Bryn Mawr College. August, 1894.

William S. Bayley, Ph. D., ~~Waterville, Me.; Professor of Geology in Colby~~ University. December, 1888. Lehigh Univ., South Bethlehem

*George F. Becker, Ph. D., Washington, D. C., U. S. Geological Survey.

Joshua W. Beede, Ph. D., Bloomington, Ind.; Instructor in Geology, Indiana University. December, 1902.

Robert Bell, C. E., M. D., LL. D., Ottawa, Canada; Acting Director of the Geological and Natural History Survey of Canada. May, 1889.

Charles P. Berkey, Ph. D., New York city; Columbia University. August, 1901.

Samuel Walker Beyer, Ph. D., Ames, Iowa; Assistant Professor in Geology, Iowa Agricultural College. December, 1896.

Arthur Bibbins, Ph. B., Baltimore, Md.; Instructor in Geology, Woman's College. December, 1903.

Albert S. Bickmore, Ph. D., American Museum of Natural History, New York; Professor in charge of Department of Public Instruction. December, 1889.

Irving P. Bishop, 109 Norwood Ave., Buffalo, N. Y.; Professor of Natural Science, State Normal and Training School. December, 1899.

*John C. Branner, Ph. D., Stanford University, Cal.; Professor of Geology in Leland Stanford, Jr., University.

Albert Perry Brigham, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

Alfred Hulse Brooks, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1899.

Ernest Robertson Buckley, Ph. D., Rolla, Mo.; State Geologist and Director of Bureau of Geology and Mines. June, 1902.

*Samuel Calvin, Iowa City, Iowa; Professor of Geology and Zoology in the State University of Iowa; State Geologist.

Henry Donald Campbell, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

Marius R. Campbell, U. S. Geological Survey, Washington, D. C. August, 1892.

Franklin R. Carpenter, Ph. D., 1420 Josephine St., Denver, Colo.; Mining Engineer. May, 1889.

Ermine C. Case, Ph. D., Milwaukee, Wis.; Instructor in State Normal School. December, 1901.

*T. C. Chamberlin, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

Clarence Raymond Claghorn, B. S., M. E., 812 Real Estate Building, Philadelphia, Pa. August, 1891.

*William Bullock Clark, Ph. D., Baltimore, Md.; Professor of Geology in Johns Hopkins University; State Geologist.

John Mason Clarke, A. M., Albany, N.Y.; State Paleontologist. December, 1897.

J. Morgan Clements, Ph. D., 11 William St., New York city. December, 1894.

Collier Cobb, A. B., A. M., Chapel Hill, N. C.; Professor of Geology in University of North Carolina. December, 1894.

Arthur P. Coleman, Ph. D., Toronto, Canada; Professor of Geology, Toronto University, and Geologist of Bureau of Mines of Ontario. December, 1896.

George L. Collie, Ph. D., Beloit, Wis.; Professor of Geology in Beloit College. December, 1897.

Arthur J. Collier, A. M., S. B., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. June, 1902.

*Theodore B. Comstock, Sc. D., Los Angeles, Cal.; Mining Engineer.

*Francis W. Cragin, Ph. D., Colorado Springs, Colo.; Professor of Geology in Colorado College.

Alja Robinson Crook, Ph. D., Evanston, Ill.; Professor of Mineralogy and Economic Geology in Northwestern University. December, 1898.

*William O. Crosby, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.

Whitman Cross, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

Garry E. Culver, A. M., 1104 Wisconsin St., Stevens Point, Wis. December, 1891.

Edgar R. Cumings, Ph. D., Bloomington, Ind.; Assistant Professor of Geology, Indiana University. August, 1901.

*Henry P. Cushing, M. S., Adelbert College, Cleveland, Ohio; Professor of Geology, Western Reserve University.

*Nelson H. Darton, United States Geological Survey, Washington, D. C.

*William M. Davis, S. B., M. E., Cambridge, Mass.; Sturgis-Hooper Professor of Geology in Harvard University.

David T. Day, Ph. D., U. S. Geol. Survey, Washington, D. C. August, 1891.

Orville A. Derby, M. S., Sao Paulo, Brazil; Director of the Geographical and Geological Survey of the Province of Sao Paulo, Brazil. December, 1890.

* Joseph S. Diller, B. S., U. S. Geological Survey, Washington, D. C.

Edward V. d'Invilliers, E. M., 506 Walnut St., Philadelphia, Pa. Dec., 1888.

Richard E. Dodge, A. M., Teachers' College, West 120th St., New York city; Professor of Geography in the Teachers' College. August, 1897.

Noah Fields Drake, Ph. D., Tientsin, China; Professor of Geology in Imperial Tientsin University. December, 1898.

Charles R. Dryer, M. A., M. D., Terre Haute, Ind.; Professor of Geography, Indiana State Normal School. August, 1897.

* Edwin T. Dumble, Austin, Texas; State Geologist.

* William B. Dwight, Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.

Arthur S. Eakle, Ph. D., Berkeley, Cal.; Instructor in Mineralogy, University of California. December, 1899.

Charles R. Eastman, A. M., Ph. D., Cambridge, Mass.; In Charge of Vertebrate Paleontology, Museum of Comparative Zoology, Harvard University. December, 1895.

* George H. Eldridge, A. B., U. S. Geological Survey, Washington, D. C.

Arthur H. Elftman, Ph. D., 706 Globe Building, Minneapolis, Minn. December, 1898.

* Benjamin K. Emerson, Ph. D., Amherst, Mass.; Professor in Amherst College.

* Samuel F. Emmons, A. M., E. M., U. S. Geological Survey, Washington, D. C.

John Eyerman, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

Harold W. Fairbanks, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

* Herman L. Fairchild, B. S., Rochester, N. Y.; Professor of Geology in University of Rochester.

J. C. Fales, Danville, Ky.; Professor in Centre College. December, 1888.

Oliver C. Farrington, Ph. D., Chicago, Ill.; In charge of Department of Geology, Field Columbian Museum. December, 1895.

August F. Foerste, Ph. D., 417 Grand Ave., Dayton, Ohio; Teacher of Sciences. December, 1899.

William M. Fontaine, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

* Persifor Frazer, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Horticultural Society of Pennsylvania.

* Homer T. Fuller, Ph. D., Springfield, Mo.; President of Drury College.

Myron Leslie Fuller, S. B., U. S. Geological Survey, Washington, D. C. December, 1898.

Henry Stewart Gane, Ph. D., Santa Barbara, Cal. December, 1896.

Henry Gannett, S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

* Grove K. Gilbert, A. M., LL. D., U. S. Geological Survey, Washington, D. C.

Adam Capen Gill, Ph. D., Ithaca, N. Y.; Assistant Professor of Mineralogy and Petrography in Cornell University. December, 1888.

L. C. Glenn, Ph. D., Nashville, Tenn.; Professor of Geology in Vanderbilt University. June, 1900.

Charles H. Gordon, Ph. D., Socorro, N. Mex.; Professor of Geology, New Mexico School of Mines. August, 1893.

Amadeus W. Grabau, S. B., Columbia University, New York city; Lecturer on Paleontology. December, 1898.

Ulysses Sherman Grant, Ph. D., Evanston, Ill.; Professor of Geology, Northwestern University. December, 1890.

Herbert E. Gregory, Ph. D., New Haven, Conn.; Assistant Professor of Physiography, Yale University. August, 1901.

George P. Grimsley, Ph. D., Morgantown, W. Va.; Assistant State Geologist, Geological Survey of West Virginia. August, 1895.

Leon S. Griswold, A. B., 238 Boston St., Dorchester, Mass. August, 1902.

Frederic P. Gulliver, Ph. D., St. Mark's School, Southboro, Mass. August, 1895.

Arnold Hague, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

*Christopher W. Hall, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

Gilbert D. Harris, Ph. B., Ithaca, N. Y.; Assistant Professor of Paleontology and Stratigraphic Geology, Cornell University. December, 1903.

John Burchmore Harrison, M. A., F. I. C., F. G. S., Georgetown, British Guiana; Government Geologist. June, 1902.

John B. Hastings, M. E., 1645 E. Thirteenth Ave., Denver, Colo. May, 1889.

*Erasmus Haworth, Ph. D., Lawrence, Kans.; Professor of Geology, University of Kansas.

C. Willard Hayes, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

*Angelo Heilprin, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.

Richard R. Hice, B. S., Beaver, Pa. December, 1903.

*Eugene W. Hilgard, Ph. D., LL. D.; Berkeley, Cal.; Professor of Agriculture in University of California.

Frank A. Hill, Roanoke, Va. May, 1889.

*Robert T. Hill, B. S., U. S. Geological Survey, Washington, D. C.

Richard C. Hills, Mining Engineer, Denver, Colo. August, 1894.

*Charles H. Hitchcock, Ph. D., LL. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

William Herbert Hobbs, Ph. D.; Madison, Wis.; Professor of Mineralogy and Petrology, University of Wisconsin; Assistant Geologist, U. S. Geological Survey. August, 1891.

*Levi Holbrook, A. M., P. O. Box 536, New York city.

Arthur Hollick, Ph. B., N. Y. Botanical Garden, Bronx Park, New York; Instructor in Geology, Columbia University. August, 1893.

*Joseph A. Holmes, Saint Louis, Mo.; Chief of Department of Mines and Metallurgy, Universal Exposition; State Geologist and Professor of Geology, University of North Carolina.

Thomas C. Hopkins, Ph. D., Syracuse, N. Y.; Professor of Geology, Syracuse University. December, 1894.

*Edmund Otis Hovey, Ph. D., American Museum of Natural History, New York city; Associate Curator of Geology.

*Horace C. Hovey, D. D., Newburyport, Mass.

Ernest Howe, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

*Edwin E. Howell, A. M., 612 Seventeenth St. N. W., Washington, D. C.

Lucius L. Hubbard, Ph. D., LL. D., Houghton, Mich. December, 1894.

Joseph P. Iddings, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

A. Wendell Jackson, Ph. B., 432 Saint Nicholas Ave., New York city. December, 1888.

Robert T. Jackson, S. D., 9 Fayerweather St., Cambridge, Mass.; Instructor in Paleontology in Harvard University. August, 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

Alexis A. Julien, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

*James F. Kemp, A. B., E. M., Columbia University, New York city; Professor of Geology.

Charles Rollin Keyes, Ph. D., Socorro, N. Mex.; President State School of Mines. August, 1890.

Frank H. Knowlton, M. S., Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. May, 1889.

Edward Henry Kraus, Ph. D., Ann Arbor, Mich.; Assistant Professor of Mineralogy, University of Michigan. June, 1902.

Henry B. Kümmel, Ph. D., Trenton, N. J.; State Geologist. December, 1895.

*George F. Kunz, A. M. (Hon.), Ph. D. (Hon.), care of Tiffany & Co., 15 Union Square, New York city.

George Edgar Ladd, Ph. D., Rolla, Mo.; Director School of Mines. August, 1891.

J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

Alfred C. Lane, Ph. D., Lansing, Mich.; State Geologist of Michigan. December, 1889.

Daniel W. Langton, Ph. D., Fuller Building, New York city; Mining Engineer. December, 1889.

Andrew C. Lawson, Ph. D., Berkeley, Cal.; Professor of Geology and Mineralogy in the University of California. May, 1889.

Willis Thomas Lee, M. S., Phœnix, Ariz.; Assistant Geologist, U. S. Geological Survey. December, 1903.

Charles K. Leith, Ph. D., Madison, Wis.; Assistant Professor of Geology, University of Wisconsin. December, 1902.

Arthur G. Leonard, Ph. D., Grand Forks, N. Dak.; Professor of Geology and State Geologist, State University of North Dakota. December, 1901.

Frank Leverett, B. S., Ann Arbor, Mich.; Geologist, U. S. Geological Survey. August, 1890.

William Libbey, Sc. D., Princeton, N. J.; Professor of Physical Geography in Princeton University. August, 1899.

Waldemar Lindgren, M. E., U. S. Geological Survey, Washington, D. C. August, 1890.

George Davis Louderback, Ph. D., Reno, Nev.; Professor of Geology, University of Nevada. June, 1902.

Robert H. Loughridge, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

Thomas H. Macbride, A. M., Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

Richard G. McConnell, A. B., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

James Rieman Macfarlane, A. B., 100 Diamond St., Pittsburg, Pa. August, 1891.

* W J McGee, 1901 Baltimore St., Washington, D. C.

William McInnes, A. B., Geological Survey Office, Ottawa, Canada; Geologist, Geological and Natural History Survey of Canada. May, 1889.

Peter McKellar, Fort William, Ontario, Canada. August, 1890.

Curtis F. Marbut, A. M., State University, Columbia, Mo.; Instructor in Geology and Assistant on Missouri Geological Survey. August, 1897.

Vernon F. Marsters, A. M., Bloomington, Ind.; Professor of Geology in Indiana State University. August, 1892.

George Curtis Martin, Ph. D., Washington, D. C.; U. S. Geological Survey. June, 1902.

✓ Edward B. Mathews, Ph. D., Baltimore, Md.; Instructor in Petrography in Johns Hopkins University. August, 1895.

✓ William D. Matthew, Ph. D., New York city; Associate Curator in Vertebrate Paleontology, American Museum of Natural History. December, 1903.

P. H. Mell, M. E., Ph. D., Clemson College, S. C.; President of Clemson College. December, 1888.

Warren C. Mendenhall, B. S., 1108 Braly Building, Los Angeles, Cal.; Geologist U. S. Geological Survey. June, 1902.

✓ John C. Merriam, Ph. D., Berkeley, Cal.; Instructor in Paleontology in University of California. August, 1895.

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✓ George P. Merrill, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

Arthur M. Miller, A. M., Lexington, Ky.; Professor of Geology, State University of Kentucky. December, 1897.

Willet G. Miller, M. A., Toronto, Canada; Provincial Geologist of Ontario. December, 1902.

* Frank L. Nason, A. B., West Haven, Conn.

✓ Frederick H. Newell, B. S., U. S. Geological Survey, Washington, D. C. May, 1889.

John F. Newsom, A. M., Stanford University, Cal.; Associate Professor of Metallurgy and Mining. December, 1899.

✓ William H. Niles, Ph. B., M. A., Boston, Mass.; Professor, Emeritus, of Geology, Massachusetts Institute of Technology; Professor of Geology, Wellesley College. August, 1891.

William H. Norton, M. A., Mount Vernon, Iowa; Professor of Geology in Cornell College. December, 1895.

✓ Charles J. Norwood, Lexington, Ky.; Professor of Mining, State College of Kentucky. August, 1894.

✓ Ezequiel Ordonez, Esquela N. de Ingeneiros, City of Mexico, Mexico; Geologist del Instituto Geologico de Mexico. August, 1896.

* Amos O. Osborn, Waterville, Oneida county, N. Y.

✓ Henry F. Osborn, Sc. D., Columbia University, New York city; Professor of Zoology, Columbia University. August, 1894.

Charles Palache, B. S., University Museum, Cambridge, Mass.; Instructor in Mineralogy, Harvard University. August, 1897.

*Horace B. Patton, Ph. D., Golden, Colo.; Professor of Geology and Mineralogy in Colorado School of Mines.

Frederick B. Peck, Ph. D., Easton, Pa.; Professor of Geology and Mineralogy, Lafayette College. August, 1901.

Samuel L. Penfield, Ph. B., M. A., New Haven, Conn.; Professor of Mineralogy, Sheffield Scientific School of Yale University. December, 1899.

Richard A. F. Penrose, Jr., Ph. D., 1331 Spruce St., Philadelphia., Pa. May, 1889.

George H. Perkins, Ph. D., Burlington, Vt.; State Geologist. Professor of Geology, University of Vermont. June, 1902.

Joseph H. Perry, 276 Highland St., Worcester, Mass. December, 1888.

Louis V. Pirsson, Ph. D., New Haven, Conn.; Professor of Physical Geology, Sheffield Scientific School of Yale University. August, 1894.

*Julius Pohlman, M. D., University of Buffalo, Buffalo, N. Y.

John Bonsall Porter, E. M., Ph. D., Montreal, Canada; Professor of Mining, McGill University. December, 1896.

Joseph Hyde Pratt, Ph. D., Chapel Hill, N. C.; Mineralogist, North Carolina Geological Survey. December, 1898.

*Charles S. Prosser, M. S., Columbus, Ohio; Professor of Geology in Ohio State University.

*Raphael Pumpelly, U. S. Geological Survey, Dublin, N. H.

Frederick Leslie Ransome, Ph., D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

Harry Fielding Reid, Ph. D., Johns Hopkins University, Baltimore, Md. December, 1892.

William North Rice, Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

Charles H. Richardson, Ph. D., Hanover, N. H.; Instructor in Chemistry and Mineralogy, Dartmouth College. December, 1899.

Heinrich Ries, Ph. D., Cornell University, Ithaca, N. Y.; Assistant Professor in Economic Geology. December, 1893.

*Israel C. Russell, LL. D., Ann Arbor, Mich.; Professor of Geology in University of Michigan.

*James M. Safford, M. D., LL. D., Dallas, Texas.

Orestes H. St. John, Raton, N. Mex. May, 1889.

*Rollin D. Salisbury, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

Frederick W. Sardeson, Ph. D., Instructor in Paleontology, University of Minnesota, Minneapolis, Minn. December, 1892.

Frank C. Schrader, M. S., A. M., U. S. Geological Survey, Washington, D. C. August, 1901.

Charles Schuchert, New Haven, Conn.; Curator, Geological Department, Yale University. August, 1895.

William B. Scott, Ph. D., 56 Bayard Ave., Princeton, N. J.; Blair Professor of Geology in College of New Jersey. August, 1892.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1899.

*Nathaniel S. Shaler, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.

George Burbank Shattuck, Ph. D., Baltimore, Md.; Associate Professor in Physiographic Geology, Johns Hopkins University. August, 1899.

Edward M. Shepard, A. M., Springfield, Mo.; Professor of Geology, Drury College. August, 1901.

Will H. Sherzer, M. S., Ypsilanti, Mich.; Professor in State Normal School. December, 1890.

* Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

* Eugene A. Smith, Ph. D., University, Tuscaloosa county, Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

Frank Clemes Smith, B. S., Harrisburg, Arizona; Mining Engineer. December, 1898.

George Otis Smith, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1897.

William S. T. Smith, Ph. D., 2630 Haste St., Berkeley, Cal. June, 1902.

*John C. Smock, Ph. D., Trenton, N. J.; State Geologist.

Charles H. Smyth, Jr., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

Henry L. Smyth, A. B., Cambridge, Mass.; Professor of Mining and Metallurgy in Harvard University. August, 1894.

Arthur Coe Spencer, B. S., Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1896.

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Joseph Stanley-Brown, 128 Broadway, New York. August, 1892.

Timothy William Stanton, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. August, 1891.

*John J. Stevenson, Ph. D., LL. D., New York University; Professor of Geology in the New York University.

William J. Sutton, B. S., E. M., Victoria, B. C.; Geologist to E. and N. Railway Co. August, 1901.

Joseph A. Taff, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

James E. Talmage, Ph. D., Salt Lake City, Utah; Professor of Geology in University of Utah. December, 1897.

Ralph S. Tarr, Cornell University, Ithaca, N. Y.; Professor of Dynamic Geology and Physical Geography. August, 1890.

Frank B. Taylor, Fort Wayne, Ind. December, 1895.

William G. Tight, M. S., Albuquerque, N. Mex.; President and Professor of Geology, University of New Mexico. August, 1897.

*James E. Todd, A. M., Vermilion, S. Dak.; Assistant Geologist, U. S. Geological Survey.

*Henry W. Turner, B. S., U. S. Geological Survey, San Francisco, Cal.

Joseph B. Tyrrell, M. A., B. Sc., Dawson, Y. T., Canada. May, 1889.

Johan A. Udden, A. M., Rock Island, Ill.; Professor of Geology and Natural History in Augustana College. August, 1897.

Edward O. Ulrich, D. Sc., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

* Warren Upham, A. M., Librarian Minnesota Historical Society, St. Paul, Minn.

* Charles R. Van Hise, M. S., Ph. D., Madison, Wis.; President University of Wisconsin; Geologist, U. S. Geological Survey.

Frank Robertson Van Horn, Ph. D., Cleveland, Ohio; Professor of Geology and Mineralogy, Case School of Applied Science. December, 1898.

Thomas Wayland Vaughan, B. S., A. M., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1896.

*Anthony W. Vodges, San Diego, Cal.; Captain Fifth Artillery, U. S. Army.

* Marshman E. Wadsworth, Ph. D., State College, Pa.; Professor of Mining and Geology, Pennsylvania State College.

* Charles D. Walcott, LL. D., Washington, D. C.; Director U. S. Geological Survey.

Thomas L. Walker, Ph. D., Toronto, Canada; Professor of Mineralogy and Petrography, University of Toronto. December, 1903.

Charles H. Warren, Ph. D., Boston, Mass.; Instructor in Geology, Massachusetts Institute of Technology. December, 1901.

Henry Stephens Washington, Ph. D., Locust, Monmouth Co., N. J.; August, 1896.

Thomas L. Watson, Ph. D., Blacksburg, Va.; Professor of Geology in Virginia Polytechnic Institute. June, 1900.

Walter H. Weed, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

Fred. Boughton Weeks, Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

Samuel Weidman, Ph. D., Madison, Wis.; Geologist, Wisconsin Geological and Natural History Survey. December, 1903.

Stuart Weller, B. S., Chicago, Ill.; Instructor in University of Chicago. June, 1900.

Lewis G. Westgate, Ph. D., Delaware, Ohio; Professor of Geology, Ohio Wesleyan University.

Thomas C. Weston, 76 Saint Joachim St., Quebec, Canada. August, 1893.

David White, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey, Washington, D. C. May, 1889.

* Israel C. White, Ph. B., Morgantown, W. Va.

* Robert P. Whitfield, Ph. D., American Museum of Natural History, 78th St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

* Edward H. Williams, Jr., A. C., E. M., Andover, Mass.

* Henry S. Williams, Ph. D., Ithaca, N. Y.; Professor of Geology and Head of Geological Department, Cornell University.

Bailey Willis, U. S. Geological Survey, Washington, D. C. December, 1889.

Samuel W. Williston, Ph. D., M. D., Chicago, Ill.; Professor of Paleontology, University of Chicago. December, 1889.

Arthur B. Willmott, M. A., Sault Ste. Marie, Ontario, Canada. December, 1899.

Alfred W. G. Wilson, Ph. D., Montreal, Ont., Canada. Demonstrator in Geology, McGill University. June, 1902.

Alexander N. Winchell, Doct. U. Paris, Butte, Mont.; Professor of Geology and Mineralogy, Montana State School of Mines. August, 1901.

* Horace Vaughn Winchell, Butte, Montana; Geologist of the Anaconda Copper Mining Company.

* Newton H. Winchell, A. M., Minneapolis, Minn.; editor *American Geologist.*

*Arthur Winslow, B. S., 84 State St., Boston, Mass.

John E. Wolff, Ph. D., Harvard University, Cambridge, Mass.; Professor of Petrography and Mineralogy in Harvard University and Curator of the Mineralogical Museum. December, 1889.

Robert S. Woodward, C. E., Columbia University, New York city; Professor of Mechanics and Mathematical Physics, Columbia University. May, 1889.

Jay B. Woodworth, B. S., 24 Langdon St., Cambridge, Mass.; Instructor in Harvard University. December, 1895.

Albert A. Wright, Ph. D., Oberlin, Ohio; Professor of Geology in Oberlin College. August, 1893.

Frederic E. Wright, Ph. D., U. S. Geological Survey, Washington, D. C. December, 1903.

*G. Frederick Wright, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

William S. Yeates, A. B., A. M., Atlanta, Ga.; State Geologist of Georgia. August, 1894.

FELLOWS DECEASED

*Indicates Original Fellow (see article III of Constitution)

*Charles A. Ashburner, M. S., C. E. Died December 24, 1889.
Charles E. Beecher, Ph. D. Died February 14, 1904.
Amos Bowman. Died June 18, 1894.
*J. H. Chapin, Ph. D. Died March 14, 1892.
George H. Cook, Ph. D., LL. D. Died September 22, 1889.
*Edward D. Cope, Ph. D. Died April 12, 1897.
Antonio Del Castillo. Died October 28, 1895.
*Edward W. Claypole, D. Sc. Died August 17, 1901.
*James D. Dana, LL. D. Died April 14, 1895.
George M. Dawson, D. Sc. Died March 2, 1901.
Sir J. William Dawson, LL. D. Died November 19, 1899.
*Albert E. Foote. Died October 10, 1895.
N. J. Giroux, C. E. Died November 30, 1890.
*James Hall, LL. D. Died August 7, 1898.
John B. Hatcher, Ph. B. Died July 3, 1904.
*Robert Hay. Died December 14, 1895.
David Honeyman, D. C. L. Died October 17, 1889.
Thomas Sterry Hunt, D. Sc., LL. D. Died February 12, 1892.
*Alpheus Hyatt, B. S. Died January 15, 1902.
Joseph F. James, M. S. Died March 29, 1897.
Wilbur C. Knight, B. S., A. M. Died July 28, 1903.
Ralph D. Lacoe. Died February 5, 1901.
*Joseph Le Conte, M. D., LL. D. Died July 6, 1901.
*J. Peter Lesley, LL. D. Died June 2, 1903.
Henry McCalley, A. M., C. E. Died November 20, 1904.
Oliver Marcy, LL. D. Died March 19, 1899.
Othniel C. Marsh, Ph. D., LL. D. Died March 18, 1899.
James E. Mills, B. S. Died July 25, 1901.
*Henry B. Nason, M. D., Ph. D., LL. D. Died January 17, 1895.
*Peter Neff, M. A. Died May 11, 1903.

*John S. Newberry, M. D., LL. D. Died December 7, 1892.
* Edward Orton, Ph. D., LL. D. Died October 16, 1899.
* Richard Owen, LL. D. Died March 24, 1890.
William H. Pettee, A. M. Died May 26, 1904.
* Franklin Platt. Died July 24, 1900.
* John Wesley Powell, LL. D. Died September 23, 1902.
* Charles Schaeffer, M. D. Died November 23, 1903.
Charles Wachsmuth. Died February 7, 1896.
Theodore G. White, Ph. D. Died July 7, 1901.
* George H. Williams, Ph. D. Died July 12, 1894.
* J. Francis Williams, Ph. D. Died November 9, 1891.
* Alexander Winchell, LL. D. Died February 19, 1891.

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